CHNOLOGY DEPT.

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Plastics

ALING WITH THE MANUFACTURE, USES AND POTENTIALITIES OF PLASTIC MATERIALS

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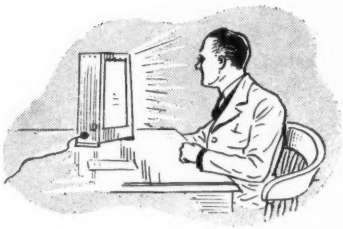

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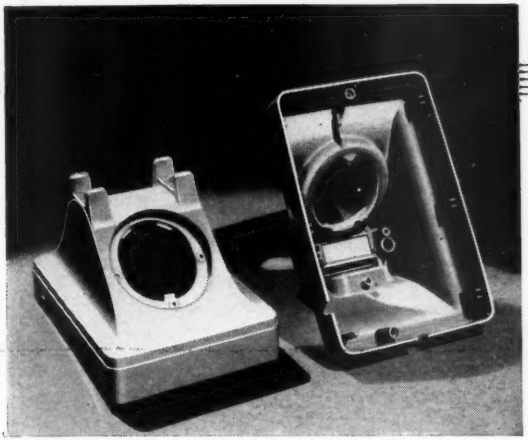

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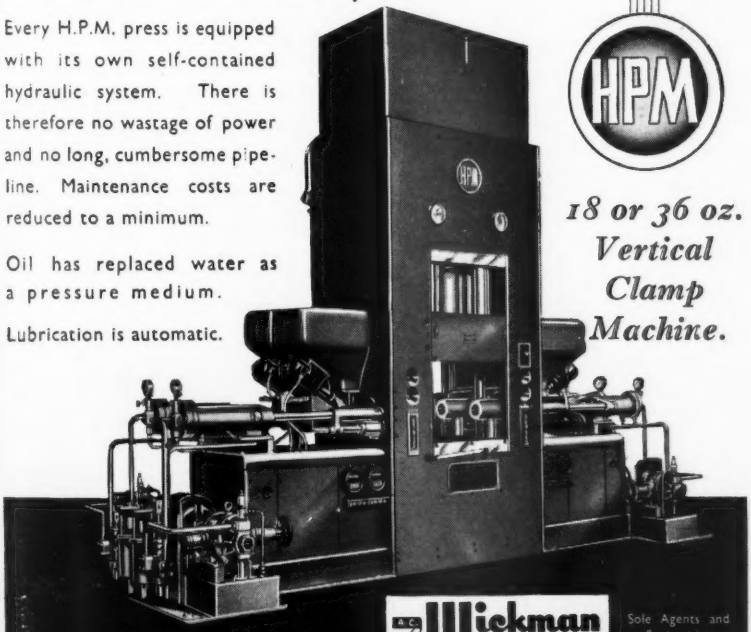

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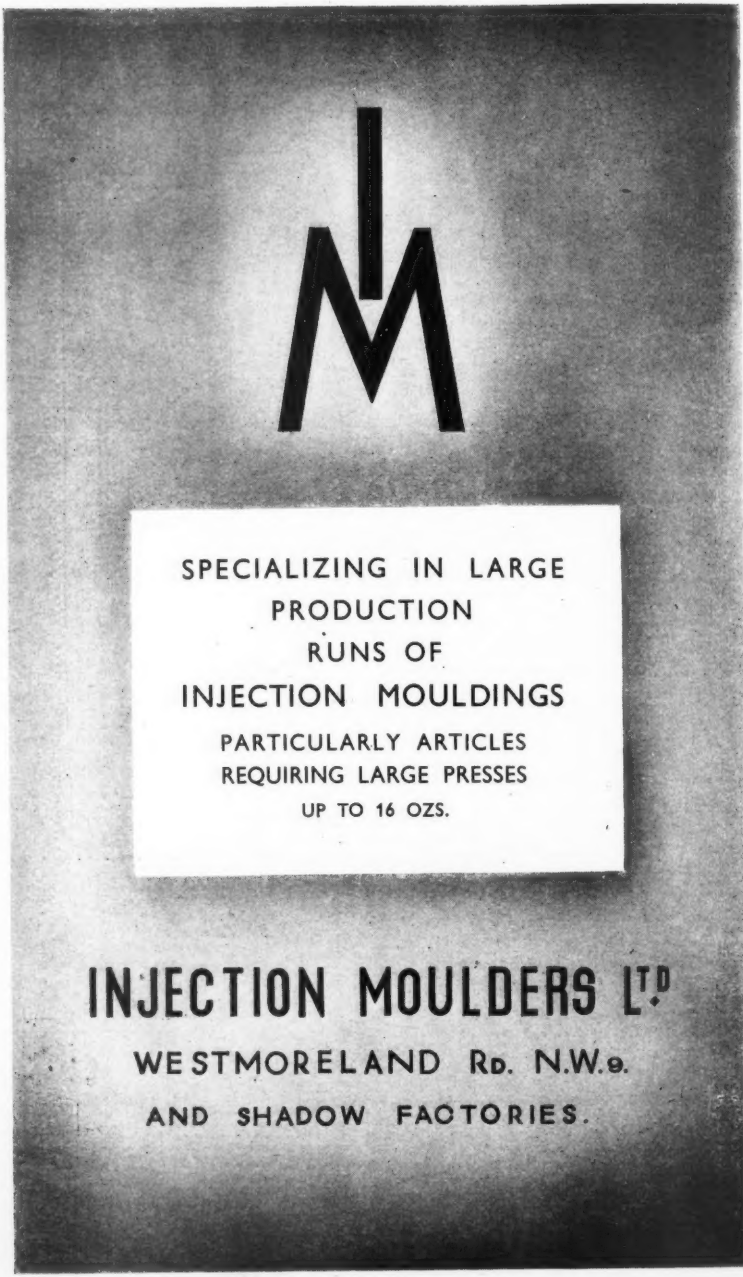
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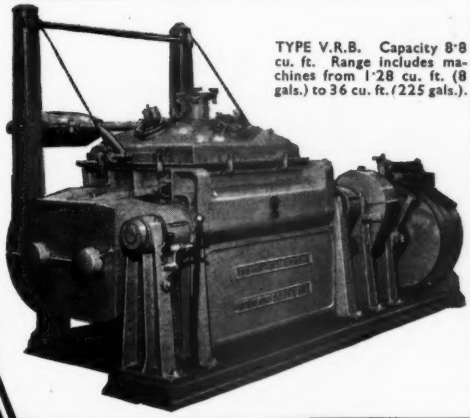

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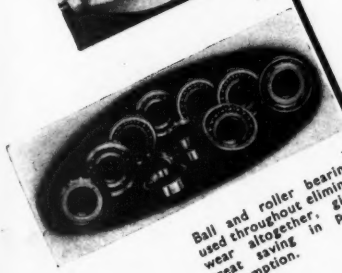

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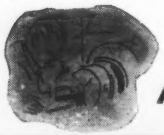
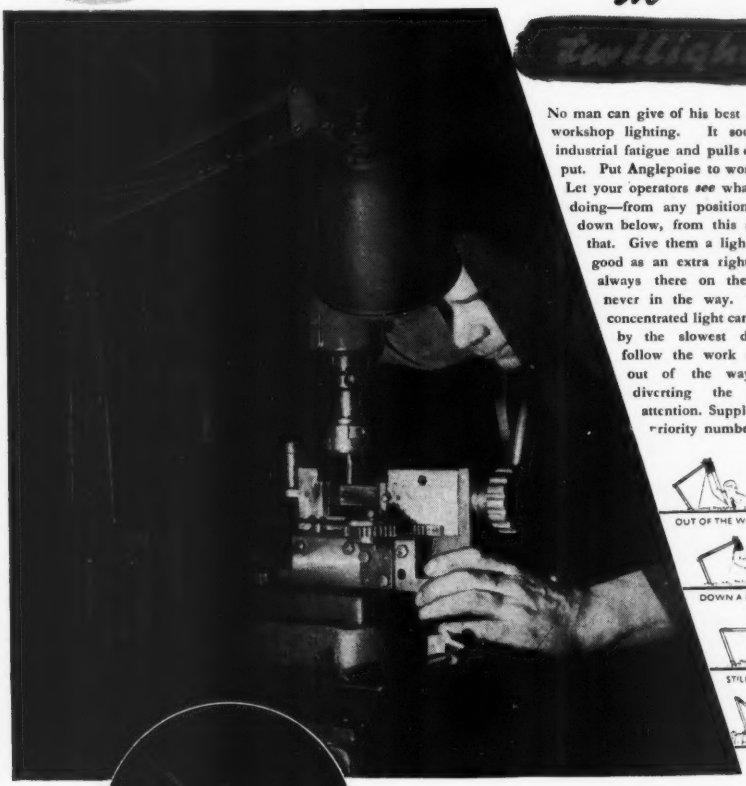


ARE YOUR WORKERS WORKING *in* *twilight?*



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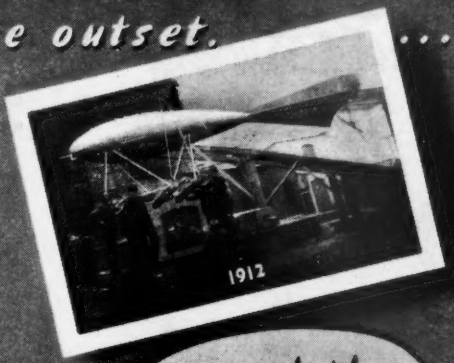

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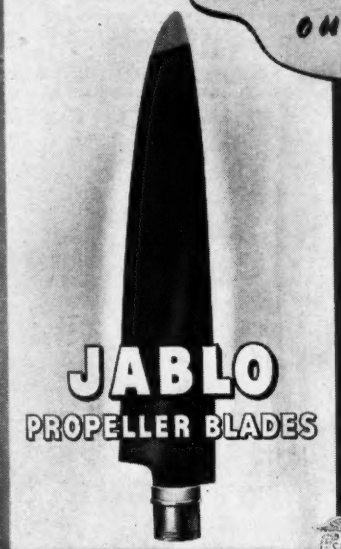

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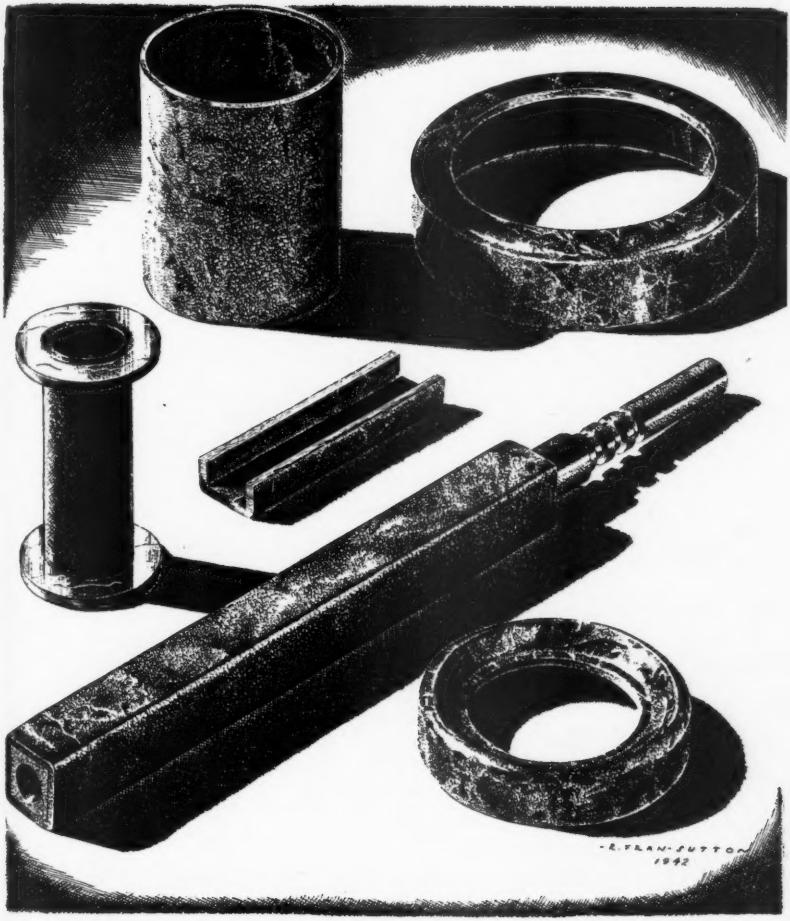

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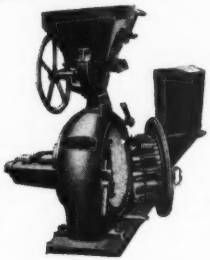

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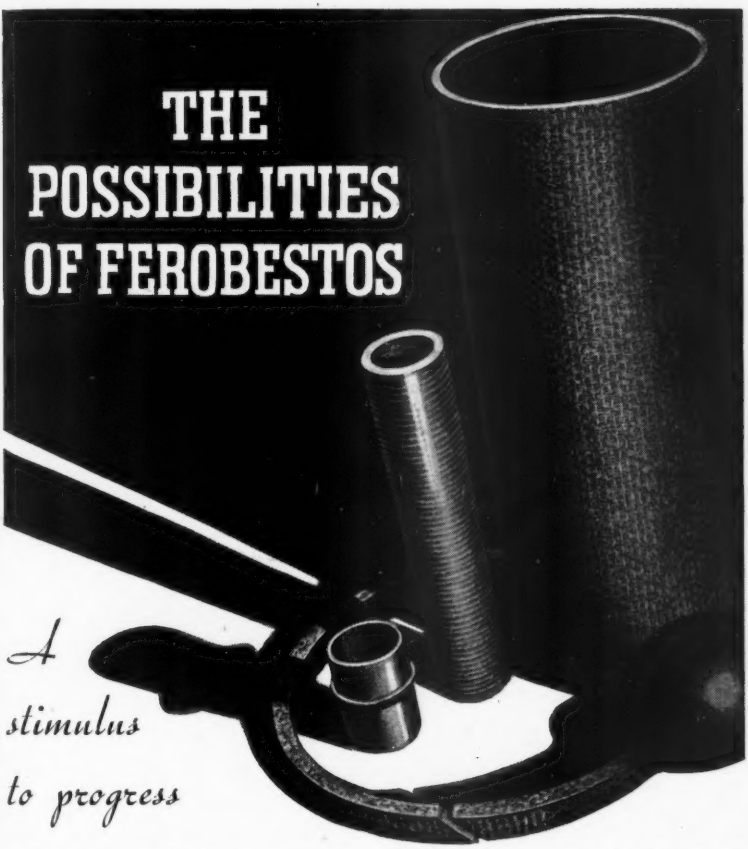

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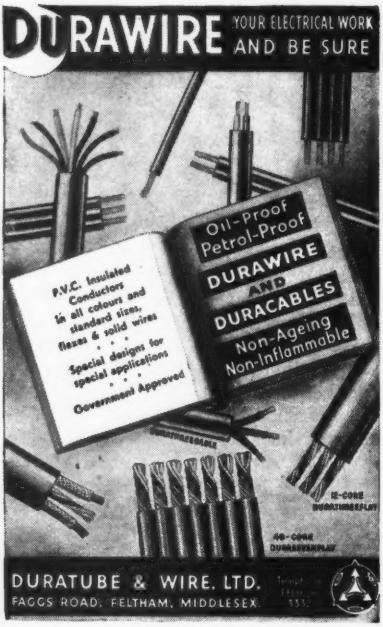
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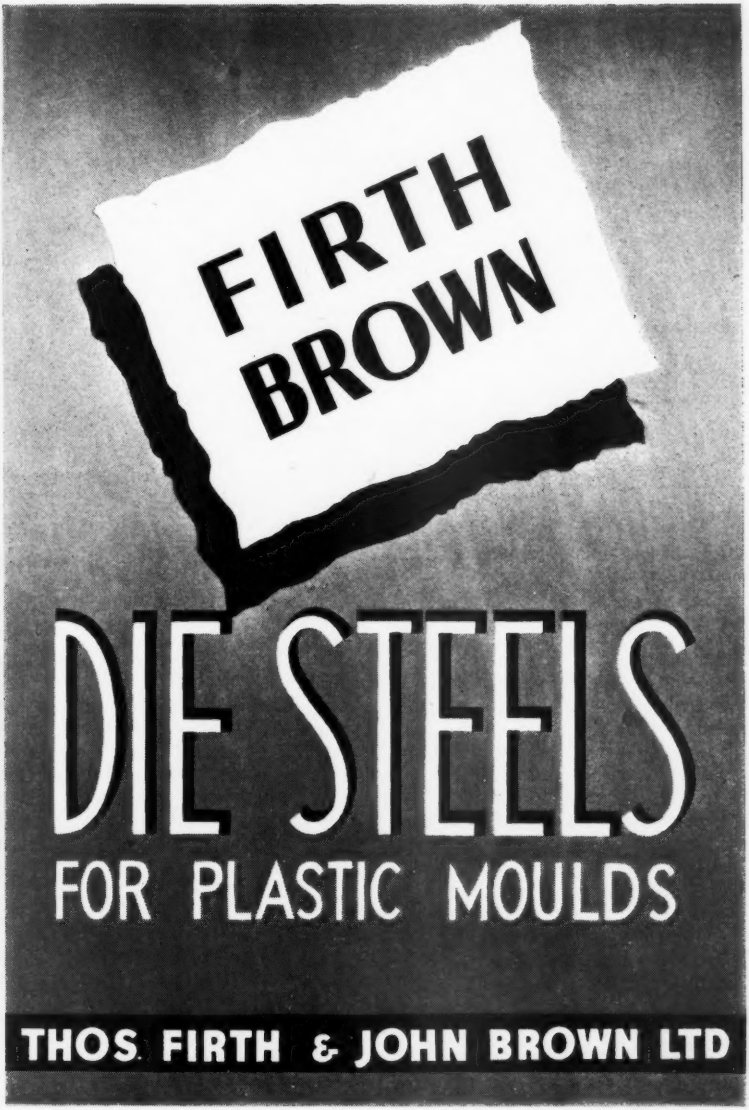
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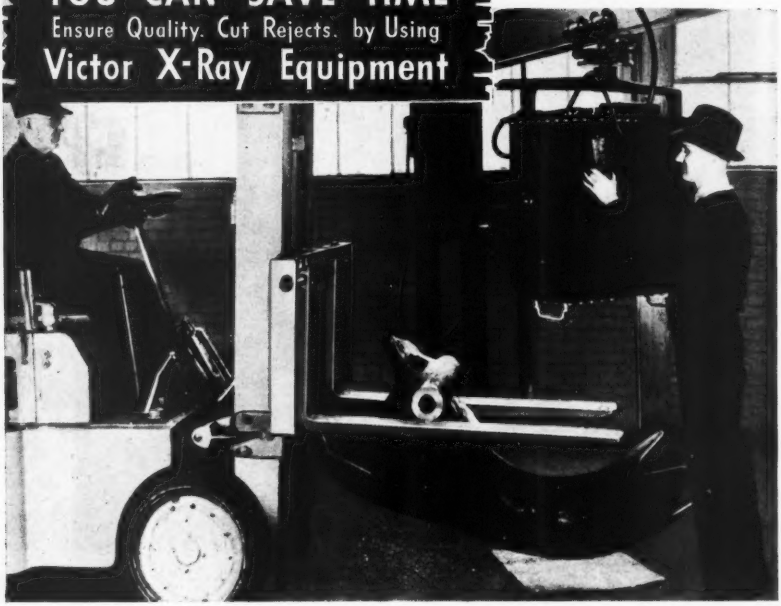

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Vol. VII. No. 79 DECEMBER, 1943

Plastics

Dealing with the Manufacture, Uses and Potentialities of Plastic Materials

Proprietors - - TEMPLE PRESS LIMITED
Managing Director - ROLAND E. DANGERFIELD

Editor - M. D. CURWEN, B.Sc., A.I.C.
Offices - Bowling Green Lane, London, E.C.1

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NOTICES

All instructions, matter and passed proofs for all kinds of advertisements must reach the Head Office of "PLASTICS" by the 24th of each month to ensure insertion in the following month's issue.

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The fact that goods made of raw materials in short supply because of war conditions are advertised in this journal should not be taken as an indication that they are necessarily available for export.

EDITORIALS

The Life of Petroleum

IN our last issue we wrote some notes under the heading of " Petroleum and Plastics," and pointed out the danger of putting one's eggs into a single basket by creating main industries based on petroleum, the sources of which may within measuring distances dry up in the great producing countries. We placed this time at somewhere within the next 30 years.

At the moment of going to press, we hear that Mr. Ickes, Secretary of the Interior and Petroleum Co-ordinator in the United States, has uttered a world warning that the United States is running out of oil and will be exhausted of it in 14 years. This is bad news for the United States, and equally so for the whole world.

However, this must not be interpreted as being anything indicative of a collapse of the energy producing or new chemical industries based on petroleum immediately after that period. There is much more petroleum to be found, and research will discover far more efficient fuels than we use now. For example, already " triptane," the new supergasoline, will carry an aeroplane two to three times as far as does octane fuel. This type of research will continue successfully, and Mr. Ickes's figures cannot have taken it into account. Nevertheless, the warning is there for all to read.

We have been criticized as being inconsistent in demanding that British plastics, for example synthetic rubber, be made from petroleum while we point out the end of petroleum. This may be paradoxical, but it is not inconsistent with our demand for training our technologists in the production of large molecules, and is quite consistent with our support of Dr. Tugenhat's statement that true petroleum refineries producing valuable chemicals can be economically run in this country. How much truer will it be, since the comparison is always made with the United States, when that country is forced to import her oil from far-off South America or from Arabia!

As a corollary we might add that it is quite clear that there will still be the necessity of maintaining our rubber trees, which will continue to provide this useful material long after the subterranean pools of petroleum of the world have dried up.

British Synthetic Rubber

AT long last the Government has announced, with supreme reluctance we should say, the granting of a licence to British Celanese to proceed with the manufacture of synthetic rubber. Mr. Lyttelton, Minister of Production, has now authorized the issue of the first requirements of material. While we can breathe a sigh of relief at this concession, it makes us wonder if the shilly-shallying and incompetence in coming to a decision for years past is an example of Government methods we may expect in the forthcoming nationalized millennium. We must have nationalization for some branches of industrial endeavour, but they will be in a state of chaos if such dilatory methods are persisted in. We cannot believe that such methods exist in all Governments—it must be the fault of individuals. What else can we think when we read of the following discussion in Parliament?

Mr. Shinwell: Can you say what is the amount of production it is intended to experiment with? Is it to be on a large or a small scale?

Mr. Lyttelton: I cannot from memory give the exact production, but it is a commercial production and not experimental.

What a reply by a man who has had

the problem and the Celanese offer before him for months, if not years!

And again:—

Mr. Shinwell: Do I understand you will encourage this for all you are worth?

Mr. Lyttelton: I must encourage it only to the extent that it does not interfere with work of a higher priority.

What verve and what impartiality Mr. Lyttelton displays to a potential industry that cannot possibly rank in priority with those war-winning industries, the production of lipstick and deodorants for the N.A.A.F.I., diamond regimental badges and hair cream.

The method of production to be used by British Celanese is quite secret, but in a letter to "The Financial News" in July, 1942, a director of the company pointed out that for the synthetic production, oil from coal could be used, and he gave production estimates based on the production of one ton from 4½ tons of coal, and that with an expenditure of about £4,000,000 an output of 36,000 tons a year of synthetic material could be reached. The claim was made that it would compete in price with natural rubber in peace-time.

High Shock-Resisting Mouldings—at Last!

FRESH conceptions of strength may be expected in the field of plastic mouldings from the recent introduction of a string filled moulding material by Cellomold, Ltd., under their designation "Rockite" 3932. This is a patented phenol-formaldehyde material, which can be moulded practically with the ease of a woodflour filled material and yet give the impact resistance of a fully laminated moulding.

The need for improved shock resistance has been amply demonstrated in this country and in the U.S.A. by the tendency to make increasing use of fabric based laminated mouldings, in cases where the highest impact strength obtainable is necessary, in order to make the moulded article a safe proposition. The ramifications of the new material in this direction will be obvious, especially in view of the limitations associated with the fully laminated moulding technique.

The material contains a string filler impregnated with a phenolic-type resin specially developed for the purpose, and in appearance it rather resembles broken Shredded Wheat. In the moulding operation the string-like elements of filler become closely intertwined, thus providing strength, yet without any tendency to form laminations or pockets in which gases can be trapped. Hence there is no tendency to blistering, and mouldings may be ejected without chilling.

It is not necessary to pre-form the material beyond the application of simple hand pressure to bind the pre-weighed charge of material in the manner of making a snowball. Pre-warming is not essential for normal mouldings in 3932, but, as with all moulding materials, flow in complicated shapes is assisted thereby. Curing times are the same as for ordinary woodflour or flock-filled mouldings.

The impact strength of 3932, according to the B.S.S.771 method of test, is 2.5-3.0 ft./lb., which is approximately 20 times the strength of an ordinary woodflour filled material, and about the same

General Characteristics of Rockite 3932

Specific gravity	1.36
Bulk factor	Approx. 7½ to 1 (after compression by hand)
Moulding contraction	0.004 in.-0.005 in. per inch.
Impact strength	2.5-3.0 ft./lb.
Tensile strength	5,500-6,500 lb./sq. in.
Plastic yield at 100 degrees C. ...	1 mm.-2 mm.
Cross breaking strength	8,500-10,000 lb./sq. in.
Water absorption	300-450 mgm.

strength as fully laminated mouldings. The requirement for the strongest grade in B.S.S.771, i.e., H.S., is 0.9 ft./lb., which represents roughly the highest standard in phenol-formaldehyde moulding materials obtainable heretofore.

The remaining characteristics of 3932 are given on p. 529.

The amazing properties of this new material are, perhaps, most strikingly demonstrated by the simple means of dropping a moulding from a height on to a concrete floor. Under conditions where a standard woodflour-filled moulding is completely shattered, and a medium shock-resisting material displays extensive crack development, such maltreatment fails to have any serious effect upon the same article moulded in the new "Rockite" 3932.

Double-dyed Black Market

YOU know well enough, dear reader, that Plastics Control has restricted the use of cellulose acetate, and it has been wisely ordained that ordinary spectacle frames are undoubtedly of high priority both for Service and civilian needs. On the other hand, the octagonal shapes, which are rightly A1 priority for Hollywood stars in their studious moments, and the very thick type known as "library" sets, which are equally rightly A1 priority for Hollywood directors, are entirely forbidden in this country. In other words, these types consume too much cellulose acetate in their making, and those females who wish to attract more attention to themselves than they normally do, and those men who wish us to believe that they are dynamic giants of industry, should rely on them no longer, but trust to their native genius to impress us.

Does this stop such manufacture? It does not.

If you go to a reputable optician or manufacturer you will not get such a pair. But you can if you know the ropes.

Certain queerly constituted firms have been able to run a nice little game of double dummy. Armed with Government contracts, they are able to apportion a part of the acetate obtained for them to carrying on "fashionable" frame-making.

Letter from a Correspondent

The name of one of my forebears has once again and recently been given undesirable publicity in the daily Press. My family is naturally very upset and I therefore take up my pen to write and ask if it is not possible to get this matter settled for once and for all.

To obviate the necessity of your glancing to the end of this epistle, I would say at once that I am a member of the feline race, but not, mark you, just an ordinary cat. No; I can claim direct descent from that venerable relation of mine, the original Sour Puss (as he was called by his contemporaries).

Our family records show that my great-× 21-grandfather, in the third year and prime of his life, was employed in a laboratory. One evening, attempting, in vain, of course, to make friends with a chemist, who (as they would have us believe) was working overtime, he had the misfortune to upset a bottle of formaldehyde on to the gentleman's portion of cheese, which he had brought for his supper.

In the chase that ensued, the cheese was knocked on to a hot plate, where it was put out of shape by the chemist losing his balance and sitting on it.

Finally, however, my relation was ungratefully chased out of the laboratory, and the chemist, by nature optimistic, returned to partake of what he thought would by then have become a tasty Welsh rarebit. But, as we all know, instead of a succulent supper he found a fully moulded ashtray.

Truth, they say, is stranger than fiction, but you will appreciate how hurt my family feel when we sometimes read in the papers that it was a mouse who discovered plastics. If this was so, how do you account for my relation's title of "Sour Puss," knowing, as we do, that all plastics are made of sour milk?

THOMAS DE HYDRATED.

POLYTHENE

Great Britain's Outstanding Contribution to the Production of High Polymers for Electrical and Chemical Resistance

A YEAR or two ago we referred to the advent of polythene upon the industrial scene, but had little data to present to our readers. Through the kindness of I.C.I. (Plastics), Ltd., we are now able to tell a more complete story of this material, which, incidentally, has provided this country with the means of producing certain electrical devices for high-frequency and high-voltage work which greatly augment our war effort.

Polythene (sold under the trade name of "Alkathene") is a general term for a range of solid polymers of ethylene, first discovered and prepared in I.C.I. Research Laboratories by subjecting ethylene gas (which can be obtained either from the combustion of coal or by the cracking of petroleum or from alcohol) to extremely high pressures. The polymer is a saturated straight chain hydrocarbon in which the individual molecules are of the order of 1,000 carbon atoms long, a structure associated with great water resistance and excellent electrical properties. "Alkathene" is a translucent thermoplastic, extremely tough and flexible, and relatively easy to process by extrusion, compression and injection moulding, by machining and welding. It is available in a coarse moulding powder form, as rod (from ½-in. to 3-in. diameter) and film 3 to 12 mils. thick. There are four grades, each of different average molecular weight.

Properties of "Alkathene"

In a previous issue we referred to some of the outstanding electrical characteristics of polythene. To these (see Table 1) we are now able to add some figures regarding chemical and mechanical properties which give a guide to the uses to which the new material may be put.

The electrical characteristics may be considered in relation to the extremely low water absorption given under chemical properties.

Table 1.

Power factor	Under 0.0001 at 50 c.p.s. and 20 degrees C. Under 0.0005 at 2×10^7 c.p.s.
Dielectric constant	2.3 at 20 degrees C.
Surface resistivity	10^{14} ohms.
Volume resistivity	3×10^{17} ohm.-cm.
Breakdown voltage	1,000 volts/mil.

Mechanical Properties

Tensile Strength. The tensile strength at break lies between 1,300 and 1,700 lb./sq. in. at 20 degrees C. and 2,000 lb./sq. in. at 0 degree C.

Cold Drawing. On stretching "Alkathene" exhibits cold drawing resulting in increased tensile strengths up to about 15,000 lb./sq. in. calculated on the reduced cross-sectional area.

Cold Flow. The polymer is remarkably free from cold flow. For example, with loads varying from 142 lb./sq. in. to 426 lb./sq. in. at 50 degrees C., for one of the softer grades the per cent. elongation/hour = 0.0012 to 0.0060. For the harder grades the figure is even lower.

Impact Strength. The impact strength is very high. If a 0.55-in. square section test piece be broken on a 150-ft. lb. Avery machine, one grade absorbs 40 ft. lb. while a harder grade absorbs about 200 ft. lb.

Chemical Properties

To many readers the remarkable chemical resistance of "Alkathene" will prove more interesting than even the excellent electrical properties. The chemical industry now has at its disposal an organic moulding and film-forming material which can withstand strong oxidizing acids (see Table 2).

"Alkathene" is also extremely water resistant, a well-moulded specimen of this material showing no gain in weight after seven days' immersion in water at all temperatures up to 100 degrees C.

Applications

At the present time the use of "Alkathene" is, generally speaking, restricted to those electrical applications where power loss is to be as low as possible, that is in the production of high-frequency cables, etc., for submarine work, bushings for high-voltage work and condenser dielectrics.

The general industrial use of this polymer seems equally bright. It has already been employed for producing bottle stoppers, the material itself acting as a seal and thus eliminating the necessity of a special liner, while acid containers which resist even fluorine and hydrofluoric acid, have also been made. The lining of chemical plant is also indicated.

As a water-resisting material, for the protection of valuable machinery or food in hot and humid atmospheres, it has a future of great promise.

Its lovely translucent appearance, white or coloured, will make it attractive after the war as a tough moulding material for containers and fancy goods.

Table 2.

Reagent	Temperature	Effect on "Alkathene"
All concentrated mineral acids	Room	None after several months
50% NaOH solution		
Hydrogen fluoride	Room	Slow discoloration but no disintegration
Concentrated HCl solution		
Dilute HNO_3 and H_2SO_4 solutions	100° C.	None after 24 hours
50% NaOH solution		
Concentrated HNO_3	100° C.	Some discoloration
Concentrated H_2SO_4	100° C.	Some charring

Specific Gravity and Housing

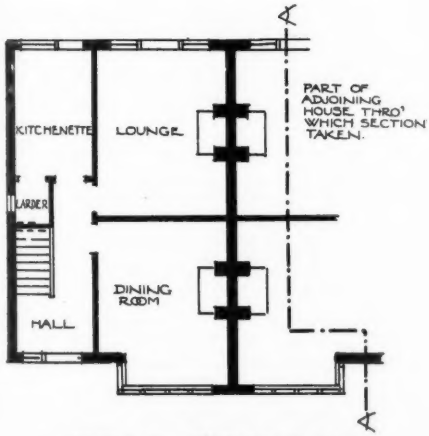
The Author, a Well-known Building Consultant, Elaborates on the Problem of Weight and its Effect on Building. He Gives Us an Insight of the Viewpoint of the Builder as Distinct from that of the Architect

by

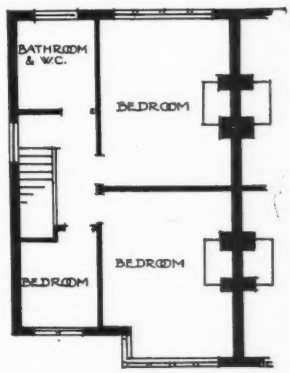
R. V. BOUGHTON, A.I.Struct.E.

THE Editorial in the November issue of "Plastics" which referred to my recent letter in the "Daily Telegraph," has given me an opportunity of providing augmenting information to further the efforts of those who place the national housing interests as of paramount importance. As a building and not a plastics man, it is only right to state that all I know of plastics is that they are contributing in many ways, some really remarkable, to the betterment of building, and that the potentials of plastics are interesting and important. Apart from the many equipmental items of a building, there is the range of sheet finishing and decorative plastics, and, what is of extreme importance, the laminated resin-bonded materials, which include structural plywoods, are creating considerable opportunities in permitting houses to be designed and constructed in accordance with the best modern codes of practice. What has always impressed me is the fact that those furthering the interests of plastics make no fantastic claims for it as a structural material—as plastics research progresses we of the building world are given reliable data to work upon. This gives the utmost confidence to all builders, and, to my mind, indicates the lines of progress in the plastics industry which will be able in the future to provide what is wanted to assist in the betterment of building.

Building, before this war, was the third



GROUND STOREY PLAN.



FIRST STOREY PLAN

Figs. 1 and 2.—Plans of the typical 1919-1939 houses weighing from 125 tons upwards according to size and built in hundreds of thousands.

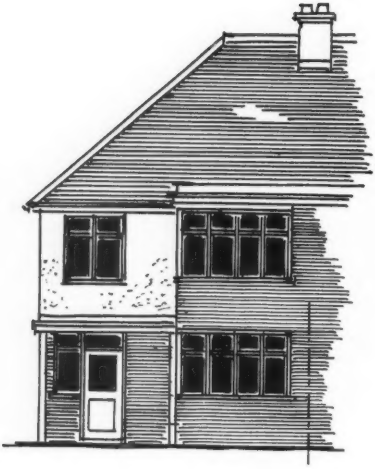


Fig. 3.—Typical front elevation of the house shown by Figs. 1 and 2.

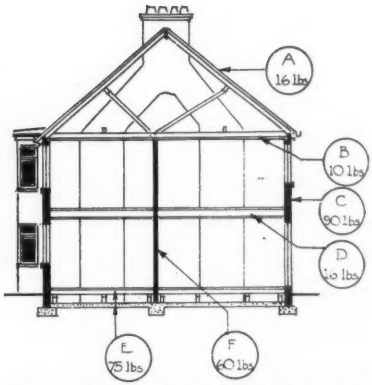


Fig. 4.—Section of the 1919-1939 type of house shown by Figs. 1 to 3.

A, 10½-in. × 6½-in. tiles on 1-in. × ¾-in. tiling battens supported by 4-in. × 2-in. rafters. B, 4-in. × 2-in. ceiling joists lathed and plastered. C, 9-in. brick wall plastered internally. D, 8-in. or 9-in. × 2-in. floor joists with ¾-in. or 1-in. wood flooring and lathed and plastered ceiling. E, ¾-in. or 1-in. wood flooring on 4-in. × 2-in. floor joists, the latter supported by wall plates on sleeper walls which in their turn are supported by 6-in. (or 4-in.) thick surface concrete.

greatest industry of the country, and its many interests are very powerful. In the post-war decades the vast programme of building will probably move it up to the status of the greatest industry, especially if progressive modernists can convince Authority that many traditional methods of construction and materials must be discarded in favour of those which are much better. This change-over will mean an uphill fight; but I am convinced that useless traditional methods and materials will, in the near future, be deemed antiques, just as surely as were horses, wooden ships and balloons.

Traditional houses have been with us too long. One hundred and 25 tons of house to house 5 or 6 tons of humans and their furniture is, without doubt, preposterous in the face of modern research and thought. It is surely utterly ridiculous to permit 4,000,000 houses, each weighing at least 125 tons, and which must be built with the utmost speed in the post-war early years, to be the only solution when better methods are at hand. As I stated in "The Daily Telegraph," and also in many technical journals, houses infinitely better than those of bricks and mortar, etc., can be built speedily and weigh about 40 tons each. The difference between 125 and 40 tons is 85 tons, which, multiplied by 4,000,000, equals 340,000,000 tons, and, allowing a very low indeed average rate of 5s. per ton for transport, the huge total of £85,000,000 is involved. And this huge total does not allow for handling costs at sites; nor does it include labour in laying, fixing, assembling, etc.

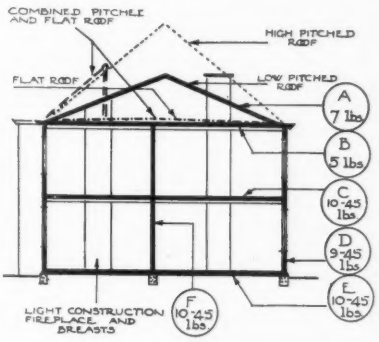
The whole subject demands the fullest investigation by minds which are quite unbiased, minds which are not controlled by vested interests, but minds which are fully alive to the fact that houses can be, and have been, designed which are cheaper, stronger, lighter, and have even a longer life than the well-built traditional houses, and a much longer and trouble-free life than the 1919-1939 jerried trash.

The weight of traditional houses may now be considered in view of the above

general outline of conditions which I have given purposely to enable the mind to grasp the importance of the subjects.

Figs. 1 and 2 depict the ground and first storey plans of a typical pre-war house, such as were built in hundreds of thousands, to, or very similar to, the plans shown. Fig. 3 shows an example of the front elevation, and in the great number of houses mentioned the variations in elevational treatment consisted of different shapes of bays, the addition of gables, and the high traditions and æsthetics of Tudor architecture and in half-timbered work upheld by ¾-in. thick rough boards, tarred and nailed to brickwork with a few cheap nails! Fig. 4 shows a section through the house. The plans and section give an idea of the weight of the house, which is about 125 tons. The figures in circles denote the approximate dead weight in lb. per foot super of the main structural parts and their various coverings and finishings. Of course, these weights can only be considered approximate as so much depends on the various materials which are used; but, to be quite fair to the traditional brick-built house, I may say my figures are under- rather than over-estimated, and, as regards Fig. 5, 40 tons is on the full side.

Exceptionally interesting and important subjects may now be considered in relation to the house shown in Figs. 1 to 4. The general stability of the structure of the walls, floors and roof rely to a great extent on the heavy weight of the walls to prevent the house collapsing; I state "to a great extent" meaningly, because the extent of stability depends on how the floors are connected to and give lateral support to the walls, and how the roof is designed and constructed to prevent roof thrusts, tending to overturn the walls. Therefore it will be manifest that the secret of stability is not heavy dead-weight; that heavy dead-weight can be useless in many ways, and that proper design, framing and jointing of comparatively light materials will ensure a structure which is much stronger than that provided by heavy materials. Surely the aeroplane is one proof of this? It is certainly time that we study most carefully the merits and demerits of various traditional materials and their uses. There is, in my opinion, no question about brickwork and concrete being used very extensively in the future; but as regards brickwork it is fallacious to consider it as the only ideal work for housing. It is very heavy, most of it absorbs water, almost like a sponge—a common brick will take up a pint. As there are about 20,000 bricks in a small house, and if it be allowed that about 10,000 of these are exposed to water



SECTION OF PREFABRICATED 40 TONS HOUSE

Fig. 5.—Section of a prefabricated house to the same plan as Figs. 1 and 2, depicting various types of roof construction.

A, Roof units of timber construction roofed with any modern type of sheet or plastic material. B, Ceiling units of timber construction ceiled with any modern type of sheet or plastic material. C, Floor units of light timber (10 lb.) or concrete or composite construction (up to 45 lb.) with flooring and ceiling of sheet and/or plastic material. D, Wall units of similar main construction as floors and covered externally and internally with sheet or plastic materials. E, Floor units similar to C but of lighter construction and without ceiling covering and waterproofed. F, Load-supporting partitions rather similar to D.

penetration in external walls and in foundations, it will be evident that even if a brick is only half saturated the weight of a house can be increased in wet weather by 5,000 × 1¼ lb., that is about 3 tons of water. This weight of water can, of course, play havoc with health, comfort, thermal acoustics and decorations. To give one instance of the vital difference between modern materials—plastics are

certainly in this category—and those of a traditional character, let us study the following: There is an American machine used to test percolation of water through various materials. This machine will usually force moisture through an ordinary brick wall in from 8 to 10 minutes; with the same pressure the machine after five days moisture only penetrated ⅛ in. through a well-known building board, and no moisture whatever went through asphalt. Manifestly, plastics can show equally good results as do building boards and asphalt.

Distribution of Weight in Traditional Type

Before passing to other methods of house construction, a few observations as to the causes of the weight of the house in Figs. 1 to 4 will be useful. First, it should be borne in mind that the 125 tons to which I have referred relates to deadweight and does not include super-imposed loads on floors and roofs which are 40 lb. per ft. super on floors and 10 lb. and 15 lb. per ft. super on roofs constructed outside and inside London respectively. Secondly, the great weight is caused chiefly by the brickwork in the comparatively thick walls and in masses to the fireplaces and chimneys; an ordinary tiled roof is exceptionally heavy in tiles, battens or boarding, and rafters, etc. An ordinary 10½-in. long by 6½-in. wide tile has usually 4 ins. of its length exposed to view and the elements, i.e., about 38 per cent., the remaining 62 per cent. being in double laps. In other words one square of 100 ft. super of roof tiling requires 555 tiles having a total area of 263 ft. super to cover 100 ft. super. Modern methods and materials do not require such wastage.

Distribution of Weight in Modern Prefabricated House

The 40-ton modern house may now be considered. It is first of all necessary for me to state that the weight of 40 tons was computed by me by allowing for the use of the best systems and materials of prefabricated design and construction. It really does not matter very much whether the weight is 35 or 45 tons—the basic fact is that it is about one-third of the weight of the traditional house. There are so many systems embracing the use of concrete, timber, resin-bonded plywood, and other materials that it would be impracticable to state any definite tonnage. As an example, the now well-known Tarran system of construction is an excellent one of good lightweight construction; the "Coventry" is another.

Fig. 5 depicts a section, which is comparable with the section shown in Fig. 4, of a prefabricated house with thin, strong, light, waterproof, and thermally and acoustically insulated external walls; similar internal partitions, floors and roof, and, as for fireplaces and chimneys, these will in the future follow methods which will be in sharp contrast to those which were inflicted on us in the past—such methods including masses of brickwork projecting into rooms, hearths projecting another 16 or 18 ins.; and fireplaces placed in most awkward and really stupid positions in small bedrooms as if their chief function is to make them quite useless except for roasting furniture and scorching bed clothes; and to allow that the majority of the heat goes up the chimney. I feel sure the future will give us the Continental system of fireplace breasts formed like radiators to ensure the maximum utilization of heat and economy in fuel.

Effect of Lightness on Foundations

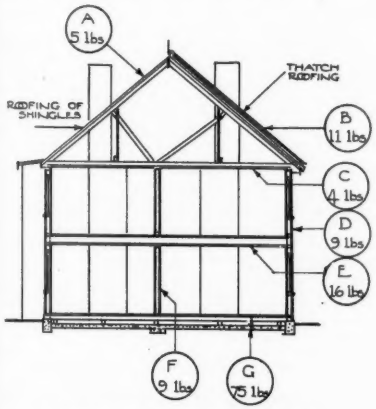
The general lightness in weight of the modern house has a most important effect on the foundations and bases. The imposition of only 40 tons, instead of 125 tons, on the foundations means considerably smaller concrete bases, and much lesser loads to cause any tendency in abnormal settlements and trouble caused by them.

I have shown four types of roofs in Fig. 5—the high-pitched, the low-pitched and flat roofs, and a combined pitched and flat roof, which is a form of design which I have recently advocated in the

technical Press. The figures in circles indicate the weight per foot super.

Plastics will no doubt make very important contributions to prefabricated housing, and I feel convinced that resin-bonded plywoods and sheet plastic materials will play important roles in structural work, finishings and æsthetical design of lightweight houses.

Prefabricated, machine-made or mass-produced houses are terms which are fluttering the dove-cotes of certain bodies and authorities who prefer to retard progress. Let us examine some of the "retarders'" unprogressive efforts to uphold traditional methods and materials and to force a resumption in the post-war decades of the 1919-1939 jerry building and those old methods which in face of modern research are now not in the best interests of those who design, construct and inhabit houses. An outline of the present schools of thought are:—

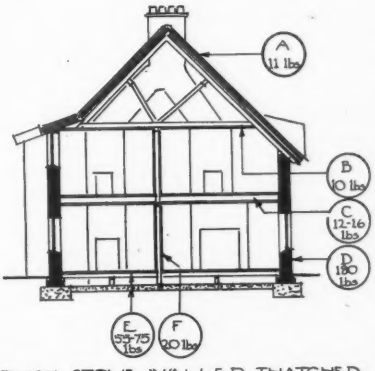


SECTION OF TIMBER HOUSE.

Fig. 6.—Section showing timber house construction to suit plans as Figs. 1 and 2 with either shingles or thatched roofing.

A, Cedar shingles (or lightweight plastic tiles) on battens and rafters. B, Thatch about 12 ins. thick on rafters, etc. C, Ceiling joists and plastic or sheet material. D, External wall constructed with timber framework covered externally with weatherboarding and internally with sheet or plastic material. E, Floor construction with timber joists, flooring and ceiling covering. F, Load-supporting partition with timber framework covered both sides with sheet or plastic material. G, Floor similar to Fig. 4.

(1) Many architects think that good æsthetics in elevational design and good planning cannot be obtained by the use of prefabricated units. We modernists feel convinced that manufacturers working in conjunction with architects can provide all that is required to achieve well-balanced and proportioned units to suit all reasonable æsthetic needs. We also are convinced that æsthetics should, to a fair extent, follow new construction methods and materials, and not the reverse. Certain recent developments tend most strongly to point to the conclusion that there are a few architects who are wise and recognize the great advantages of prefabrication and there are others who wish to retain the old methods and materials. The latter we ask: To what extent did architects exercise their powers to stop the 1919-1939 jerry building and design? Practically nothing. Are architects responsible for the great strides which have been made in construction methods and new materials during the past three decades? I fear but very little, since it is the engineers who have given us the best in



THICK STONE-WALLED THATCHED COTTAGE

Fig. 7.—Old thatched cottage.

A, Thatched roofing on rafters, etc. B, Ceiling of ceiling joists lathed and plastered. C, Floor similar to Fig. 4, but often of lighter construction, and sometimes ceilings are matchlined. D, Stone wall about 18 ins. thick. E, Floor as Fig. 4, sometimes without surface concrete. F, Partition with timber framework lathed and plastered (or matchlined) both sides.

steelwork and reinforced concrete, and manufacturers the best of innumerable new things, such as building boards, glass, floorings, wall coverings, roofings, asbestos-cement goods, and—plastics, and many others.

(2) That prefabrication means to the "man-in-the-street" nothing more or less than shacks and huts. This, of course, is a totally wrong impression, and various interests are at work to prove that the modern interpretation of prefabrication means something better than the old-fashioned method of building houses—and slums. Those various interests will show that the prefabrication or mass-production of building units is only an extension of mass-production and the use of machines which have been adopted and used in the past for manufacturing and/or preparing very many building materials such as cement, bricks, tiles, timbers, joinery, floorings, glass, metal goods, wallpapers, and so on. It is only an extension to speed up building, to ensure the proper use of the best materials, and to avoid the assembling or building of many thousands of bits and pieces with a considerable volume of water in wet mixing, often in wet or inclement weather. It is also an extension to cheapen and at the same time provide better houses.

(3) That the present building by-laws will not permit many of the new methods and materials. This is one of the weakest arguments put forward, as it is quite obvious that the authorities will amend by-laws to allow any method of construction and use of any materials which are proven to be in accordance with good codes of structural practice.

(4) That prefabricated houses will not last as long as traditional houses. This, of course, is absolute nonsense and is probably based on the erroneous idea that materials used for prefabricated units will be similar to those used for chicken runs, rabbit hutches and cheap packing cases. Materials for prefabrication can be chosen for long or short life as required, and, what is of extreme importance, they can be chosen so as to ensure consistent longevity in practically all the structural parts.

Timbered House and Thatched Cottage

The timber house.—A section of this type of house is shown by Fig. 6, and whereas its walls, partitions, floors and roof structure are of timber construction, the roofing materials may also be of timber, such as shingles, or of tiles, thatch, etc. As the weights in lb. per foot super denote it is an extremely light form of house. It is warm in winter and cool in summer.

The old thatched cottage is depicted in section only by Fig. 7. Its walls and general structure are very heavy, as the weights show; its roof is light in weight and, acoustically and thermally, most to be desired. I have lived in one, been in and examined plenty of them, and I have admired their artistic contribution to the countryside. But that's all. The drawbacks of thick walls, low storeys, miserably small windows, ground floors infected with dry rot, rocking upper floors, roof spaces the harbourage of vermin, and lack of sanitary conveniences may be considered a rather sweeping condemnation; but, in many instances, it is not too sweeping. I am sure that a thin-walled house built in accordance with modern codes can make quite as good an artistic contribution as the old thatched cottage, etc. Let us have sensible houses!

U.S. Plastics Production

At a meeting of the American Society of the Plastics Industry it was estimated that the annual sales value this year of the synthetic resin moulding industry will be of the order of **$500,000,000.**

It is also divulged that special impregnated woods have progressed very rapidly in war-time. One type termed "impreg" is wood simply soaked in a solution of phenolic resin and subjected to no pressure, and another termed "compreg" is subjected to 250 lb./sq. in. Both techniques are well known in this country.

World's Industry Employs Plastics

AIRCRAFT

Prevention of ice formation on propeller blades is said to be made possible by the provision on the leading edge of the blade of a strip of electrically conductive rubber marketed under the trade name "Uskon," by the United States Rubber Co. **Engine gasket** has been designed consisting of copper mesh coated with synthetic rubber; its thickness is only 0.015 in. The gaskets are blow-out proof and are used for sealing the crankcase of aero engines. Longer gasket life is said to be obtained with reduced oil consumption. The material is made by the Detroit Gasket and Manufacturing Co. **Antenna and Pitot mast of the Curtiss Wright aeroplane** are in the form of a single-piece moulding in phenolic resin-treated cloth. These components are said to be produced by a new technique elaborated by the Chicago Moulded Products Corporation. **Extruded components in Ameripol** have been developed for aircraft applications. As compared with natural rubber giving a durometer hardness of 40 degrees, extruded Ameripol has a durometer reading of 35 degrees. Ameripol mixes exist even at − 70 degrees F. and are so flexible that they can be bent at an angle of 90 degrees around a ½-in. rod. Such materials serve in the construction of tanks for the storage of high-octane petrol and aromatic fuels. Sealing strips of the material 1.75 in. wide by 3/32 in. thick are placed along the edges of the metal sheet which is bolted together to form the tank.

CHEMICAL

"Kem-pol," a vegetable-oil product, is offered as a replacement for natural rubber, normal synthetic rubbers and reclaimed rubbers in applications making no heavy demands on the tensile strength of the material. Several grades are available. The most viscous of the untreated polymers is ruby red to transmitted light, whereas the other grades are amber in colour. This material is said to be soluble with difficulty, if at all, in aromatic hydrocarbons.

GENERAL ENGINEERING

Proof of the wear-resistance of polyvinyl - chloride is furnished by the test carried out by Gregson, and described in "Technical Bulletin," Inst. of Prod., Eng., June, 1943. A sheet of polyvinyl-chloride ¼ in. thick was used for covering the interior of the cabinet of a continuous-type Wheelabrator, provided with three impellers, running at 11,000 r.p.m. and delivering 300 lb. of shot per minute. The polyvinyl-chloride had a life of 115 hours, compared with that of 8½ hours for special covering plates of chilled chrome iron. **Effects of resin on the properties of wood** are discussed in a comprehensive article by Casselman in "Mechanical Engineering," 1943/65/737. On page 701 of the same journal Millard describes investigation of the **fixing strength of machine**

screws in various materials. Ferrous and non-ferrous metals, various non-metallic structural materials and plastics were examined. Amongst the plastic materials were laminated (phenolic) fibre sheet (N.E.W.A. standard grade XX), Tempered Presdwood, manufactured by the Masonite Corporation, and consisting of boards made by compression of exploded soft-wood fibre; Tempered Die Stock made by the same concern from exploded hardwood fibre, and laminated Lignin plastic sheet. It was found that the phenolic sheet develops the full strength of machine screws at appreciably lower thicknesses than the other materials. With compressed boards of softwood fibre, thread engagements more than ½ in. appear to be required. The holding strength in lignin-fibre sheet approached that obtained with a phenolic sheet. **The shaping of plates and foils of polyvinyl chloride and mixed polymers formed** the subject of recommendations in a data sheet recently issued by the Plastics Committee of the German Association of Engineers (V.D.I. Verlag, 1943). An extract of these recommendations has just been issued in "V.D.I. Zeitschrift," 1943/87/346. Sheet above 0.1 mm. thick is usually shaped in the hot state. When preparing the material it should be observed that it tends to shrink longitudinally and transversely on heating, and that the thickness increases. The value of linear shrinkage of this type varies. For foils heated up to 130 degrees C. and then cooled, 2-3 per cent. shrinkage occurs in the direction of rolling and 1 per cent. shrinkage at right angles to the direction of rolling; the corresponding increase in thickness being 4-5 per cent. **Working temperatures lie between 60 and 130 degrees C., according to the type of material and its thickness.** If dimensional stability is required, working is best carried out at a high temperature, although for massive deformation lowest possible temperatures should be used. According to the type of shape to be done, either the tool, the material, or both tool and material are heated, and forming must be carried out at maximum possible speed, so for difficult work fixtures and templates must be to hand in order that the shaping process shall not be interrupted. When shaping is finished, the material should be cooled immediately by some suitable quench. For formation of bends and angles the bend radius should not be less than twice the thickness of the material being bent. In special cases only may bends as acute as equivalent plate thickness be employed. The bending zone should be heated to about 130 degrees C. for a width equivalent to six times the plate thickness. **Plates above ⅛ in. thick are better welded into bent and angular forms rather than bent from the solid,** particularly where a surface temperature above 40 degrees C. is expected, or where any hot embossing must be carried out subsequently to bending. Embossing is best carried out with punches heated to 80-90 degrees C. and applied to the cold material. For the drawing of cylindrical components material is heated to a temperature of 60-70 degrees C., the temperature of the drawing ring being about 80-90 degrees C. Clearance between punch and ring should be 20-25 per cent. smaller than the thickness of the material, and good radii should be provided to the ring to eliminate possibility of tearing. For the drawing of complicated parts the material should be heated to about 130 degrees C. and worked as quickly as possible, the work being cooled on the tool by water quenching. **Where very massive deformations are to be sustained a blank holder as in ordinary sheet metal work should be employed to avoid wrinkling.** Foil and plate may also be deformed by blowing, being heated up to 130 degrees C. and then expanded by a rubber diaphragm or directly by compressed air against an internal form. Some components can be blown directly without the use of a form. **Manufacture of curved plywood parts** was discussed by Perry in a paper before the American Society of Mechanical Engineers (abstracted in "Mechanical World," 1943/114/204). The use of the flexible-bag technique to obtain uniform hydrostatic pressure is the principle of

modern processes for the production of curved plywood parts. Of the resin-bonds available for the purpose the phenolics are most favoured, excepting for such components as deep laminated rings where heat penetration is slow.

FANCY GOODS

Printing on celluloid is discussed in "Gelatine Leim, Klebstoffe," 1942/10/98; 105. The difficulties to be overcome are noted and the need for special colours in special media is pointed out. Some degree of attack on the celluloid is essential in order that adhesion of the colours may occur. Polishing and lacquering of the finished work is touched on. **Lightning fasteners,** their history, design and production, are dealt with in "Génie Civil, 1943/70/68. The valuable part played by plastics in permitting the use of coloured fasteners is referred to at length and it is pointed out that the plastic unit can be moulded directly to the band.

MOTORS

Koroseal sponge, produced originally for military uses, is now available for essential industrial purposes. The material has been used extensively for crash padding in tanks and in helmets. Its property of non-inflammability and its self-extinguishing quality are specially to be noted. The new product can be worked up into various densities and pore sizes, and possesses the same resistance to oil, grease, chemicals and oxidation as massive Koroseal. It cannot be vulcanized, hence, for certain purposes, new production techniques have to be developed. Koroseal sponge remains soft and compressible to temperatures as low as −40 C.

MISCELLANEOUS

Solvents for collodion were studied by Kraus and reported upon in "Farben Ztg.," 1943/47/52, and in "Chem. Zbl.," 1942(11) / 113 / 1293. Solubility in mono- and dihydric alcohols with additions of halogenated hydrocarbons were investigated. Solubility in the monohydric series was exhibited up to $C_9H_{19}OH$. Aromatic alcohols were also shown to be suitable as solvents in certain cases, in the presence of halogenated hydrocarbons. All the glycols, with the exception of 1.5 pentadiol, proved good solvents without further additions. **Synthetic rubbers, their production, technique, manufacturers, and characteristics of finished products** are comprehensively reviewed in Information Circular 7,242, Bureau of Mines Department of Interior, Washington, D.C. **Continuously extruded plastic tube and section,** sources of supply and material types available are discussed in a publication prepared by the Thermo-plastic Division, Society of the Plastics Industry, New York. One particularly valuable section deals with suggested applications of extruded tube and section. **Natural rubber statistics** are dealt with in "Génie Civil," 1943/70/65. Production from Hevea Brasiliensis and other plants since the beginning of the war is tabulated. **Electrical classification of plastics,** principles of their production and mechanical and physical characteristics of thermoplastic materials are reviewed by Adam in "Révue Générale de l'Electricité," December, 1942. Composition and uses and, in particular, mechanical, thermal and electrical peculiarities are examined in detail. **Cultivation of Latex-bearing plants in Russia**

was dealt with by Chevalier in a recent lecture before the French Academy of Agriculture. The lecturer dwelt especially upon the possibility of eventually cultivating plants of this type in France. It was claimed that yields up to 1.5 tons per hectare were possible. **Cascophen LT-67,** produced by the Casein Co. of America, New York, is said to combine many of the desirable properties of phenolic adhesives and casein glues. The glue is said to be proof against cold water and boiling water, dry heat, extreme cold, organic solvents, moulds and bacteria. A wide range of curing temperatures is claimed. On low-density woods, such as spruce, poplar, bass, soft mahogany and douglas fir, the glue may be cured and matured at temperatures as low as 70 degrees F. Curing temperatures for hardwoods average about 110 degrees C. If necessary, however, curing may be effected at 300 degrees F. **High-frequency curing of resin-bonded wood laminates** is exhaustively dealt with in the September issue of "Modern Plastics." The technical and economic advantages of the system are analysed. **Elektron microscope studies** are described by Zworykin (Industrial Eng. Chem. Ind. Edn., 1943/35/450), who has examined lower polymers of vinyl-chloride (× 17,000), highly polymerized vinyl-chloride (× 105,000), polystyrene (× 385,000) and carbonyl-iron powder in a phenolic-resin mounting (× 6,000). **Protection of threaded parts during electro-deposition** is conferred by polymethyl methacrylate (Lucite brand) which has proved more durable than rubber, lacquered wood and many types of phenolic resin, which tend to deteriorate and contaminate the bath. The Thomas-Thiel Co., Wilmington, Del., employ plastic sheet and rod insulators in set-ups for the electro-deposition of wear-resistant chromium on steel parts. **Stock-room bin card-holder in plastics** is recommended for replacing essential metals. These cards, which are supplied in various shapes and sizes, are applicable to any flat surface by means of tacks or glue. They consist of the plastic holder, an insert tab on which may be typed descriptions of the stock, and a covering sheet of transparent plastic (Hollywood Athletic Co., Los Angeles, California). **Adhesive for production of waterproof fibre-board containers** has been developed by E. J. Dupont de Nemours. Containers, made by laminating four to eight sheets of heavy paper glued by means of the special water-soluble vinyl resin, are said to be so proof against moisture that they can withstand submerging in water for 24 hours. **Technical qualities of soft rubber** are summarized in tabular form in a comprehensive account by Roelig (V.D.I. Zeitschrift, 1943/87/347). An attempt is made to classify soft rubbers on the basis of Shore hardness. The author states that classification of elastic properties has not been given the attention the subject merits. **Moulding Powders with low resin content** have formed the subject of investigations described in "Kunststoffe," 1943/33/97 (abstracted in "V.D.I. Zeitschrift," 1943/87/358). Tests were carried out with a material containing 25 per cent. by weight only of phenolic and cresylic resin, together with coarse wood-flour or wood-chip filler. Useful properties were exhibited by this powder. The material, which has been designated Type 41, has general properties similar to those of the former S Type, containing 40-50 per cent. by weight of resin, although water absorption is higher, rising to 2 per cent. as compared with 0.5 per cent. for the higher resin content. Curiously enough, impact-strength values are superior with the low-resin moulding powder. **Hydraulic moulding presses** with the hydraulic cylinder attached to the upper framework have been standardized in Germany. Sizes have been arranged according to the series R10 in the system of preferred numbers. During war-time, only 11 sizes are to be permitted, but the peace-time programme provides 22 sizes. This development will represent a saving on the present state of affairs, with about 100 different types of presses being manufactured ("Deutsch. Reichs. und Preuss. Staatsanzeiger," No. 84, 1943, abstracted in "V.D.I. Zeitschrift," 1943/87/375).

The Future of Plastics

Notes on the Trends of the Plastics Industry, Some of which Formed the Basis of a Talk Before the Southern Section of the Institute of the Plastics Industry on November 17, in Southampton

By M. D. CURWEN, Editor of "Plastics"

WHEN the Chairman of the Southern Section of the Institute asked me to give a talk on "The Future of Plastics" I was delighted with the chance, and I must admit that in the course of my life, which has been an interesting, sometimes strange and often funny mixture of chemistry and journalism, I have always been intrigued by prophecies of the trend of sciences. If the time is placed at, say, the year 2043 or 3043, we can assume that the prophet is safe from contradiction, but if he knows his subject his story may be not only fascinating but may also serve to clear the fog of complexity from the road of progress.

Typical of the truly valuable peep into the future is J. B. S. Haldane's "Dædalus," a purely logical and simple exposition of the future of science, or more recently E. C. Large's "Sugar in the Air," a romantic and satirical story of the synthesis of sugar. Both should be on the Institute's list of books for the education of the student.

Typical of less valuable excursions of the imagination is that by the writer who presents the lives of forthcoming generations as being encased from birth to death in plastics, or that by the fellow who has just handled a cast resin ash tray and writes a brilliant article to the "Courier" demanding that London Bridge be dismantled forthwith and replaced by one made of plastics. It is difficult to decide which is the more boring. In what follows I must plead lack of vivid imagination.

To get a reasonably adequate picture of the future of the plastics industry, we must examine many of its facets—the problem of raw materials, of new types of plastics, of new processes, new applications, of research, of education. And of these I am sure that education is the most important. So let us deal with some of these problems and see where the plastics industry is driving.

The Industry of Giant Molecules

The plastics industry is, in truth, an industry of very large molecules and perhaps it may be necessary from an economic point of view to stress, from now on, the giant molecule conception at the expense of the plastic one which has been so confusing to the public. Such a nomenclature would, with careful guidance, be readily understood and would not be overburdened with ambiguity. There is, of course, a horrible danger that new companies might be floated with the awful names of "Stupendous Molecules Inc.," or "British Gigantic Plastic Moles, Ltd."

Large organic molecules have long been used by man—bitumen, only a medium-sized molecule, was easily obtained and very easily worked, as were fossil gums and resins like amber for decoration, gums for perfuming and religious purposes and fossil resins for making paints. Certainly in the early 15th century there are records that a goodly trade was carried on by heating cow-horns, twisting and moulding them and palming the results off on a simple public as genuine unicorn horns! Egg made one of the best binders that the artist could use, and so was blood which even to-day finds wide use. Silk with its excellent strength and insulating properties was quickly adopted by the electrical industry, as was shellac and cotton.

All these are large natural organic molecules.

To-day, with the exception of our casein, shellac and our cellulose-derived plastics, we generally prefer to build up our large molecules from smaller ones because we can produce purer and more consistent qualities (the natural resins were always impure and often deliberately adulterated) and moreover we can produce those with special properties we desire, a process termed tailoring the molecule to the customer's requirements.

Are we going to continue this synthesis from small molecules and will all plastics one day be synthetic?

They probably would be if they were truly synthetic, that is, if they were made from the carbon dioxide in the air or the mineral chalk, or the carbon dioxide from the waste in our chimneys, the only " free " sources of carbon in the form of a small molecule. Unfortunately nobody, except a small band of people in Liverpool University, has ever succeeded in synthesising from this source.

The Trouble We Go To!

While it is true that the chemical factories synthesising our plastics use small molecules, yet they obtain them only by breaking down larger ones first. Thus coal, the molecule of which is so large and complicated that we do not know much about it, is broken down to carbolic acid and to formaldehyde or to benzene or naphthalene or to acetylene before we can build it up into what we want, that is phenolic resin, nylon, styrene or synthetic rubber or glyptal resins. The enormous sugar molecule is broken down to alcohol and then to acetic acid, acetone, or ethylene for our cellulose acetate, our polythene plastics and our synthetic rubber.

Even the medium-sized petroleum molecule is disrupted first, and then built up into a wide range of polymers and in enormous quantities.

When a company manufacturing a commodity is first started it is axiomatic that a wide and deep survey be made regarding the availability of raw material for its processes. The plastics industry of the world has made no such survey.

How Much Raw Materials Have We?

How much petroleum and how much coal is there available in the earth for the plastics industry? A more sensible question would take the form of " How much petroleum and coal is there available for all industry? " This problem will worry us until such time as we will get a new energy for our everyday use.

I certainly cannot give the answer to either question, but it is necessary to answer it, and it is not beyond the ability of international effort to do so.

Nearly 25 years ago, when I first entered the petroleum industry, the pessimists put the life of the world's petroleum deposits at between 30 and 50 years. The first figure, which falls due in five years, is probably wrong, but what of 1968? More oil is being found, but more oil than ever is being consumed as fuel under boilers, as fuel in internal combustion engines, and will steadily increase in use as " new " countries are opened up.

The United States of America some 10 years ago began building up a chemical industry based largely on petroleum as a raw material. Canada, Russia, Germany, France, Poland, Rumania were also using petroleum for chemical manufacture, and so in a small way were we. By next year the U.S.A. alone has promised to make over three-quarters of a million tons of one plastic material—synthetic material—much of it from petroleum and it will take much more than this quantity of raw petroleum to make it. The U.S.S.R. is also progressing in this sphere. Paradoxically we too should begin to make chemicals and plastics from petroleum because this is such an excellent field to train our technologists, because economically refining even foreign crude is quite feasible and because petroleum may yet be found in districts as near to Great Britain as they are to the United States. I suggest that

a good deal of petroleum is already shipped from Arabia to the States. But we cannot eat our pudding and still have it and the world must not rely on petroleum as its main stand-by.

Coal as Britain's Raw Material?

What of coal? Here we are on somewhat surer grounds, for the coalfields of Great Britain will last us over 150 years, and if new research results in cutting out the appalling wastage that occurs in combustion and in the use of inefficient open grates, then the life of our coalfields will be much greater.

But the use of coal is not as simple as the use of petroleum. The last-named comes out of the ground in a fairly pure liquid condition by simple pumping. Coal is dug out and we get our raw materials from it by heating coal up to 1,200 degrees C., which in itself is very expensive. Not only this, but for every ton of coal we treat thus, we have left 12 cwt. of coke which is almost a drug on the market. We can expand our plants for producing more benzene, phenol, cresol, naphthalene, etc., for our plastics industry fairly readily, although the plant is expensive, but by our present methods we keep on piling up relatively useless coke.

This difficulty of expansion is somewhat in the nature of a nightmare to chemists and it is no easy matter to convince the excited journalist that his idea of immediately making moulded doors for all houses is not a good one. He tells us that 5,000,000 houses will need doors. True. Let us analyse this. The average house has about 20 doors in it, each needing about 50 lb. of material. Thus we shall require 5,000,000,000 lb. of material or 2,000,000 tons. Why, the total production of plastics in this country is only between 30,000 to 60,000 tons a year. We can readily see that even if low proportions of plastics are used in making doors in a composite structure the supply problem is not simple.

Were we able to obtain a hydrocarbon gas straight from the ground without costly coal winning and haulage and which could be converted into the materials we require, the situation would be considerably eased and we are all watching the experiments in Russia on these lines with intense interest. It seems a great pity that our coal industry, which was presented with this idea by Sir William Ramsey, did not examine it. More hopeful by far is Haldane's prophecy that new sources of energy will be discovered and instances a control of the winds and the use of surplus power to produce oxygen and hydrogen which would in turn be recombined in explosion motors. This method is of course the process employed by the Herren motor which was described at a meeting of the Institute of Chemical Engineers about the year 1930 and which has now reappeared in scientific discussions. Such a process would, as Haldane says, " shut down our coal mines to-morrow," but they might re-open as huge reservoirs for the plastics industry, and with cheap power we would one day, as somebody has impertinently but appositely remarked, get reasonably priced phenols to give truly cheap and abundant resins.

Peat May Prove Useful

Peat as a source of carbon compounds has been a disappointment in the past. Close to coal in composition and abundant, yet containing so much water so difficult to extract, it has proved the wheel on which many a pretty scheme has been broken. Efforts at peat treatment and distillation are again being renewed in Great Britain and in Russia and perhaps one day we may see the growth of a new chemical industry to help our own.

Natural Large Molecules as Direct Raw Materials

So much for our raw materials for synthetic plastics, but with our wide experience of celluloid, casein, cellulose acetate and other plastics made from naturally occurring large molecules, it would be a pity if we did not collaterally build up an even wider range of natural plastics.

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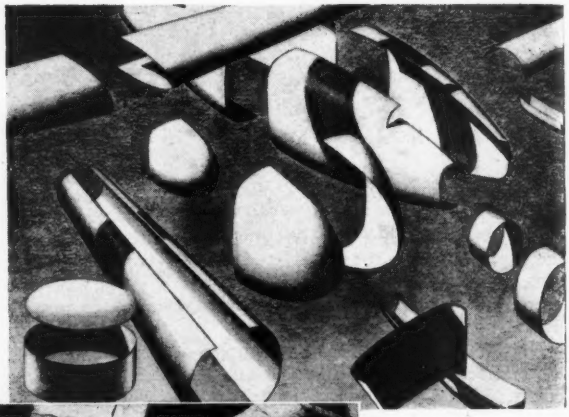
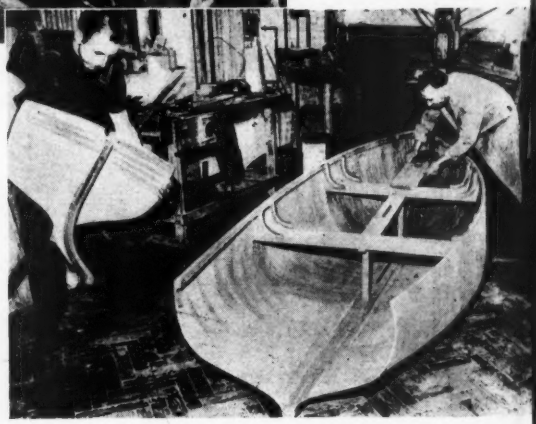


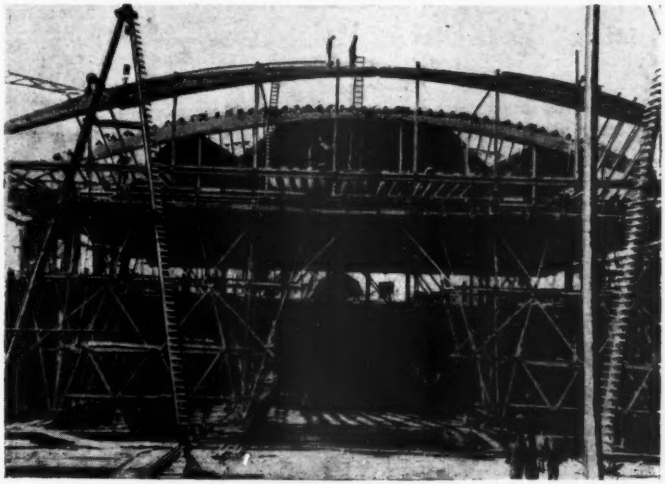
American designer's portrayal of the versatility of resin-bonded wood laminations.

(Left) Nylon may soon be free and paint brushes, bearings, ropes, webbing, washers and fabric made from it will appear

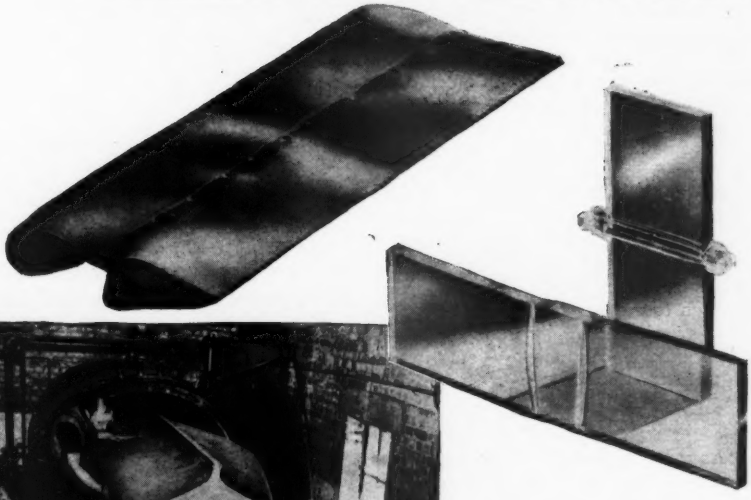
(Below) The rubber-bag low-pressure technique of bonding laminations as applied to small boat production.

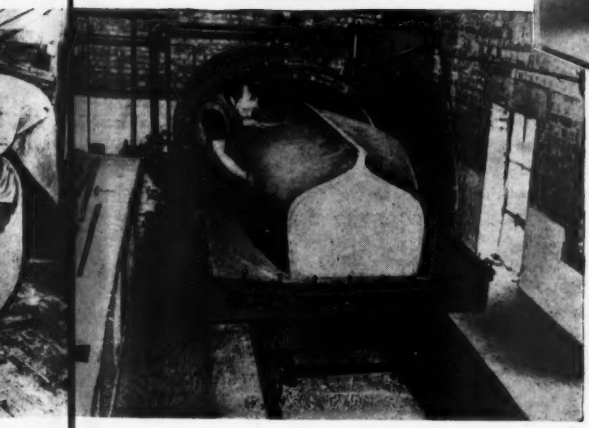


THE PROMISE OF THE FUTURE



The structural members of this fair building in Zurich were made with Melamine resin-bonded material.





(Above) Spot-welded P.V.C., and butt and lap-jointed cellulose acetate welded by the new high-frequency technique.

Wool as a Plastic

Let us take wool as an example. Chemically it has been examined only by the textile industry and only as a textile. The plastics industry has used it only as a filler and not as a giant molecule, not, in fact, as a possible plastic. Yet it is the type of molecule we are all searching for in our laboratories and in one sense is the type of molecule—the protein one—the builders of nylon were looking for. It is a very long and tough molecule, with a little kink at regular intervals to give it elasticity and, miracle of miracles, it has already got the cross linkages chemists are now trying to get into certain rubber-like materials, to give high solvent resistance. If we were to treat it as a potential plastic this great molecule would repay us amply for the trouble; if we found a true solvent for it, powdered it, plasticized it and compounded it, we should certainly be relieved of a large headache for our raw material. It will not be easy, since it is such an insoluble molecule, but I recommend this suggestion for research to the Australian Government. That country is very much concerned in the rapid growth of synthetic fibres which are ousting woollen yarns. As a lover of Australia and Australians, I for one do not regard the doom of Australian wool with anything but dismay. As the sheep is decent enough to grow wool for us, at the same time growing meat, by utilizing grass as the source of carbon, wool must not be thrown into the discard.

Silk, Keratin and Collagen

As much may be said for natural silk, another large molecule of tremendous possibilities, and although my store of brotherly love is not sufficiently large to cover Japan in its present condition, we must note its incidence in the future.

So too with the protein we obtain from skins, hides and hooves—collagen and gelatine. To date we make from them an excellent glue, a good food and a film for carrying silver particles on a photographic plate. Not a very impressive list of manufactures from a very remarkable large molecule. I say an excellent glue advisedly, and it is really that in spite of plastics. We have only to look at age-old furniture to see that. It is only inferior to the synthetic phenolic and urea glues because it is more readily attacked by water and by fungi. Something even better could be made from it if only research were carried out. There has been no research on it because it has been difficult to handle, but if I were to prophesy I should say that the large protein molecules in animal carcases, whether derived from the skin, hair, horns or hooves, will one day produce useful plastics. We must never reach the stage where we must destroy this raw material, as Brazil did her coffee because of economic changes. Of its possibilities we can say little here except that we have seen an excellent cast resin made from it by co-condensation with phenol and formaldehyde. Equally we can bring forward good arguments for research on starch, etc.

Raw Material Use by International Agreement

The Atlantic Charter promises to give all nations the chance of obtaining the raw materials they want. Perhaps one day there will be an even greater agreement, an arrangement whereby the obviously useful things in one part of the world do not vanish simply because of a discovery in another part of the world. We have not sufficient raw materials yet to afford this type of extravagance.

Synthesis of plastics—indeed synthesis of any compound—is a 20th century wonder and produces materials often better, cheaper, at a greater rate per unit area, and with the expenditure of less human energy than Nature can. Moreover, we can thus build up materials of the type we want. But it would be wrong and perhaps industrially suicidal not to look at the raw material stock sheet before we go ahead full tilt.

(The conclusion to this article dealing with new processes, etc., will be published in our next issue.)

Metallizing Plastics
(continued)

A Complete Survey and Critical Study of the Modern Methods of Metal Film Formation on Plastics for their Protection and Decoration

by
E. E. HALLS

7. Metal Films Applied by Hot Branding Processes

The expression "hot branding process" is an old-established one which has come to embrace a number of newer processes that are scientifically precise and capable of exact control. It is thus a rather crude generic description, and will perhaps be more commonly recognized as a rough and ready method of marking or branding materials such as wood, leather, and the like, than as an engineering method. From the very crude procedure of using hot stamps merely to burn an inscription on to an organic base, the method has been developed into a means of applying a range of patterns having utility or decorative qualities on to various objects and fixing them by heat to give them permanence. The utilization of the thermal agency for this latter factor, and of providing the pattern through the medium of another material rather than by the local disfigurement of the base material or object, are the fundamental principles of the modern machines. These are simple, quick operating, and designed to be very flexible in their range of operation. With very little adjustment, which can be rapidly effected, materials, hard or soft, tough or brittle, from glass to metal, including cards and plastics, can be dealt with.

The principle of the earlier processes was a press, upon the base of which the article to be imprinted with a pattern was located, and to the moving member of which was fitted a heated die carrying an engraved or embossed replica of the design. The "colour" for the design was used in the form of a thin film, this being placed on the object and the die brought down upon it. The pattern was thus stamped out and fixed upon the article. One type of film used was that known as Oeser foil, this comprising a pigment set on an adhesive backing. The pigment could be metal powder, such as finely

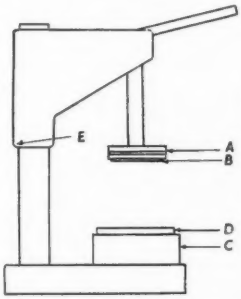


Fig. 23.—Simple form of hot press. A, electrically heated die; B, matrix; C, base or jig; D, work to be marked; E, adjustable head.

divided aluminium, one of the brasses or coppers. The film would be placed adhesive side in contact with the work. The die would be at suitable heat, from 90 degrees to 150 degrees C., according to the nature of the base material. Pressures would be of the order of 300 lb./sq. in., and the time of contact in the neighbourhood of one minute. Upon removal from the press the surface of the work would be brushed or wiped to remove loose foil from the neighbourhood of the pattern. The pattern itself would be securely fixed, but to meet very arduous service conditions it could be lacquered or varnished over, and air dried or baked according to its nature.

The essentials of a hot pressing machine of this type are shown diagrammatically in Fig. 23.

Metal powder finishes, aluminium for "silvers," brasses for "golds," and coppers in a range from natural to rose or purple, applied by processes of this type, are very attractive for decorative and advertising purposes, as well as for coding. If the impression fails in a few spots upon the first attempt it can be returned for a second impression if accurate location is maintained. Multi-metal patterns can be applied in repeat applications. Moulded plastic containers of phenolic, amino, cellulose acetate types, etc., can be mass produced in standard powders such as the dark-coloured ones very cheaply, and be given a final attractive finish by stamping all the descriptive matter, trade mark or fancy design by this means by way of relief. Cosmetics and beauty parlour goods have exploited this feature. But furniture, trays and tables, wall panellings, moulded cabinets, transparent plastic window materials, etc., can all be so patterned.

Modern Marking Foils

The most modern type of marking foil is produced in rolls about 18 ins. wide. It consists of a thin paper backing, which renders it safely handleable, coated with the pigment bonded with synthetic plastic adhesive, usually of cellulose ester base. Obviously the metal powder pigments are included in the range. This material can readily be slit to suitable width on a slitting machine, and appropriately fed to the "branding machine" and cut to length with a knife blade or guillotine.

One form of machine to deal with sheet material or flat surfaces consists of a press, somewhat similar to a letter press. The upper platten consists of an electrically heated hot plate, fitted with a thermoregulator and a temperature-indicating instrument. Thus exact temperature conditions can be maintained over a period of time. To this hot plate is clipped another plate, upon which the "type" is accurately set. The "type" may be set up from letters and figures, or it may be a specially cut metal matrix to represent an engraved scale, a pattern or other inscription. The work to be marked is located on a sliding plate that can be rapidly inserted or withdrawn over the lower platten. Accuracy of adjustment is facilitated by adjustments on the four supporting pillars of the machine. The upper platten is lowered by means of a hand-operated lever, pressure being controlled by springs or hydraulically.

Temperature range from about 90 degrees to 180 degrees C. is closely controllable. Thus the lowest limits are used for the thermoplastics and up to 110 degrees C. for the phenolics. Setting-up time is short, and operating time from a fraction of a second to about three seconds. It merely comprises that required for placing the work in position, placing the foil over the work, paper side uppermost, sliding with work into the machine, lowering and raising the lever, and withdrawing the work. The impression is securely adherent to the work, and can only with difficulty be scraped off or washed off with solvents such as cellulose thinners, white spirit, etc. For greater durability, such as resistance to oil and petrol, etc., it may be varnished or lacquered, air-dried or stoved. Impressions can be indented, this doubling the operation, that is, taking a second or so longer. The tool is brought down on to the work before the foil is placed in position, and this lightly stamps the surface. The paper is then inserted, printed in the normal way, the print filling the cavity. The same machine and pigmented foil can be used to make transfers of the slip-off variety by printing on to specially prepared thin material, which comprises a "skin" of cellulose synthetic secured to a paper backing with water-soluble adhesive. The transfer can then be soaked in water, and the print slid off on to the job and pushed into position. Upon drying it can be lacquered over with cellulose transfer varnish to hold it in position.

In the hot stamping process, providing that the press is properly set up with plattens parallel and that the tools are accurately produced, very faithful reproduction of the master is achieved. Not only lettering and figuring of all types but any pattern can be printed, including

complete areas or partial areas. Value from the decorative and printing viewpoints or for rendering a metallic appearance alone can be claimed. The coatings at present have no electrical value because conductive mixtures have not yet been developed.

8. Electroplated Metal Coatings

In order to metallize an article by electroplating methods, either it must be conductive (e.g., metals, electrode carbon, etc.) or it must be rendered electrically conducting, at least superficially. As there has always been a demand for electroplate coatings on non-metals such as the porcelains or ceramics, glasses, wax moulds and plaster castings, and the like, methods have been developed for producing conductive surfaces upon which metals can be coated by electro deposition processes. Some of these are applicable to the plastics and they will be discussed in this section. The procedures described have been, and are still, used commercially, but it is considered that they possess serious limitations which restrict their general application. Therefore, it must not be considered that they compete with the metal powder coatings applied from organic media for decorative or other purposes, nor in soundness with the true metal coatings applied from the wire, powder or molten metal spray guns. They are presented as methods used, probably capable of further development, useful when no other means of procuring the desired results is available, or for specific purposes.

Electroplating processes are primarily used for metals and have as their objective the deposition of metal coatings to protect the base material against corrosive influences or to impart an appearance of artistic or decorative value and, to lesser degree, to give properties of abrasion or wear resistance and to yield surfaces having particular electrical properties. Fundamentally, electroplating processes applied to plastics are the same as those employed for the metals, but there are obvious limitations in each of the individual operations involved. Practically all factories engaged in engineering industry possess their own plating plants; for those without such installation specialist platers are established. These concerns may or may not have knowledge of plastics and of electroplating them. Many producers and users of plastics are not familar with these matters. Therefore, a brief sketch of the essentials of the operations of plating will be given without going into detail, and the methods resorted to in the case of plastics to overcome the peculiar problems encountered here will be summarized.

In dealing with metals, whether in the form of stock or of components, plating entails preliminary cleaning, surface preparation, electro deposition, washing and drying.

Preliminary cleaning involves the removal of all extraneous matter and the provision of a chemically clean surface of the "pure base material." Loose dirt, oil and grease, rust, scale, oxides, tarnish, corrosion products and any other foreign matter must be removed. Solvents (trichlorethylene, methylated spirit, solvent naphtha, white spirit, etc.) or aqueous alkaline solutions (caustic soda, or milder mixtures of sodium carbonate, phosphate or silicate) are employed to remove grease or oil. Dilute acid solutions (hydrochloric, sulphuric or sulphuric/nitric acid mixtures) are used for rust, oxides, scale or tarnish. Generally for heavy contamination, a separate cleaning stage is instituted, the plating line proper having a final series of light cleaning operations. This is, in fact, the preferred procedure.

Work after submission to primary cleaning is racked, jigged or wired for suspension from the cathode bus bar of the plating equipment, ensuring tightness between work and jig or wire and the latter and the bus bar, to provide good electrical connection. The work is then passed through all operations without permitting drying or partial drying until electro deposition and final washing are completed.

Preliminary Cleaning

The first operations of cleaning on the plating line will, in general, include a rapid clean by immersion in hot aqueous alkali and a dilute acid pickle. The alkali is operated short of boiling and may have electrical aid with the work either anodic or cathodic. Thorough water washing to remove all alkali follows prior to immersion in the acid solution. The acid solution may have electrical aid. Thorough water washing again follows. If the plating solution itself is an acidic one work can then enter; if it is alkaline, then a rinse in dilute cold sodium cyanide solution, followed by water rinsing, is desirable. Additionally, a special acid etch, with or without electrolytic aid, may be interposed following the acid pickle; the object of this is to augment adhesion.

This series of operations ensures that the work to be plated is, first, chemically cleaned and, secondly, thoroughly wetted. Every point on the work surface is then in a condition to receive metal deposit when immersed in the plating solution and contact is made to the cathode bus bar, the current supply being already switched on.

The electrolyte in the plating bath will contain salts of the metal to be deposited as its main constituent and other ingredients for specific purposes of suppressing dissociation of the main salt, of providing conductivity, and of influencing grain size, colour, matness or brightness of the deposit. Anodes will generally be of the metal to be deposited. All electrolyte conditions have to be closely controlled; composition, temperature, filtration and agitation, anode area in relation to work area, anode spacing and disposition, current density and voltage: all these are factors to be closely set in relation to the nature of the metal plated, shape and size of the articles, the metal to be deposited and type of deposit. Plating time is that required to produce a coating of the specified thickness. Immediately after plating, water washing in cold and hot waters and then drying off rapidly is entailed. The water washing may have to be extended for 5 to 10 minutes to achieve complete removal of all chemicals.

Plating plants may be "still," semi-automatic or fully automatic. Again, for small or suitably shaped articles, barrel plating may be employed. Further, duplex coatings may be required, for example, silver-rhodium, nickel-chromium, etc, in which one plating follows the other after appropriate water rinsings.

This brief survey of electroplating, familiar and elementary to electroplaters or electrotechnicians, but foreign to many executives and technologists, has specially been included for two reasons. First, it should stress that in its obvious sphere of application to metals, a large number of individual operations are involved, and each must be carried out precisely and correctly. Secondly, it serves to show that the range of individual operations necessitated with the plastics is not foreign to electrodeposition in general and to stress the significance of each.

Before leaving the general problem of electroplating, attention is drawn to the operations of "washing." A surface of simple shape, hard and non-porous in nature, can be quickly washed, a matter of 10 secs. to 1 min. often sufficing. A porous surface requires longer, and often it is impossible to free pores in a metal surface from retained chemicals. The same applies to recesses, blind holes and overlaps. Thus trouble is usually experienced from chemicals seeping out from pores in iron castings and from the laps of spot-welded joins. At the best, the detriment from these inclusions can be minimized. In the case of plastics, porous surfaces are often presented. A low-grade, highly absorbent bakelite paper-laminated sheet cannot be plated without first "waterproofing" it because its fibrous nature causes chemical solutions to be absorbed. It is even less possible to wash these interstices than it is to free the pores of iron castings from retained chemicals. The retained chemicals not only tend to creep later, to corrode the

coating and to spoil its appearance, but also mitigate against good adhesion. On the other hand, a high-grade phenolic resin paper laminated sheet shows this fault to a much less degree; nevertheless, the possibility of absorption is there, and the extent of trouble is determined by time of immersion in, and temperature of, the chemical solutions. Moulded bakelite surfaces without cut edges exhibit this shortcoming to a still less, or even negligible degree. Cellulose acetate shows absorption which may be high but has no paper or fibrous content to accentuate it. Acrylic and polystrene resins can generally be regarded as non-absorptive.

Adhesion and Cleanliness

Another point that should be dwelt upon before passing from the plating of metals to that of the non-conducting plastics. It concerns adhesion. In the electroplating of metals, positively charged ions enter the electrolyte from the metallic anode, travel through the electrolyte with the current, and are discharged at the negatively charged cathode. Here they give up the positive charge they carry, and the adhesion of the uncharged metal deposit is a function of chemical cleanliness of the cathode, purity of the metal deposited and the rate of discharge. The latter can be arranged within the limitations of the conditions obtaining to suit the nature of the metal deposited, that upon which deposited, and the shape of the article. Thus conditions can generally be devised with relative ease whereby intimate molecular contact is achieved and a good adhesive bond of metal to metal obtained. As the deposit is thickened, practical conditions can be adjusted to suit to avoid developing strains, as, for example, by hydrogen embrittlement, and thus to prevent peeling or flaking of the component. In the case of plastics, however, limitations are more severe. A sealing coat of suitable medium has first to be applied in the case of porous articles, and then a conducting layer. Primary adhesion, therefore, is no better than the physical adhesion of these coverings. Moreover, the conducting layer will have its limitations with respect to current-carrying capacity and potential distribution, so that the same flexibility is not available for suiting electrical conditions to the other factors obtaining as it is in the case of the metals.

Processes in Plating Plastics

The plating of plastics thus entails the following processes:—

(1) Thorough cleaning to give a chemically pure surface condition.

(2) Waterproofing or sealing when necessary, dependent upon the type of plastic.

(3) Provision of an electrically conducting layer and its bonding to the surface.

(4) Electroplating proper.

(5) Final water washing and drying.

(6) Polishing, colouring or lacquering as required.

These can be discussed separately.

Precleaning should not be an arduous operation, and the previous history of the work should be so controlled to ensure that no complications are unnecessarily caused. Swarf and dust will be general contaminants. Mouldings after deflashing and definning operations will have loose pieces and dust adhering to them. They may be subjected to milling, finishing, drilling and tapping processes, and be further contaminated with swarf of the moulded material. Metal inserts, too, may be submitted to machining operations of drilling or tapping, etc., so that metal swarf then has to be contended with. Other forms of plastic material, sheet, rods, tube, angle, etc., will likewise give swarf from machining operations. Oil, wax and grease lubricants will be the other probable contaminants. Waxing of moulds for the thermosetting resins is often resorted to, in which case a film of wax will be present on the mouldings and must be removed. Most people machine the plastics dry, but some use lubricants. If plating is to follow, lubricants should be selected with a view to their easy removal in solvents. Soap

base greases and emulsion oils should be avoided, and so should tallow, because none of these is easy to wash away. Straight oils should be used, but only when essential. For example, lard oil/mineral oil mixtures, or mineral oils bodied-up with aluminium oleate or stearate (the latter being exceptions to the rule, and being soluble in solvents), suffice for the severest of tapping operations. Water or a mixture of paraffin oil and mineral oil suffices for the clean machining of acrylic resins to complicated shapes.

Under circumstances controlled in this manner, the cleaning of plastics for plating can always be achieved with organic solvent, giving special attention in the case of the thermoplastic bodies to avoid using one in which the plastic is soluble. Panels can be wiped clean using a solvent moistened cloth and small components can be mass-treated by immersion.

In all cases a double cleanse is necessary; for example, using two baths of solvent, one "dirty" for the first rinse, one "clean" for the final wash. When the second is contaminated, it is changed to the first position and replenished. Tanks should thus be of minimum volume to avoid undue wastage. Fire risk precautions need to be taken, the room in which the work is performed must be ventilated, and the operations preferably carried out under an exhaust hood. A compressed air gun is often used to assist in blowing off swarf and also for final drying off of the solvent. If it is used, the air must be clean and dry, and meticulous care taken to see that it is completely free from oil.

Organic Cleaning Solvents

With the phenolic resin plastics, mouldings or sheet types, a standard trichlorethylene liquor vapour degreasing plant is often conveniently employed for cleaning. With the higher grades, that is, relatively non-absorptive types, this is satisfactory provided that the cleaning time is rigidly kept to the minimum required.

The following are satisfactory cleaning solvents for the various plastics:—

Phenolic and amino resin products. Ebonite and hard rubbers. Cellulose acetate. Casein plastics. Acrylic resins.	White spirit or coal tar solvent naphtha.
Polystyrene, polythene and polyvinyl chloride plastics.	64 OP methylated spirit.

Drying after washing can be achieved by natural evaporation of the solvent or by forced drying in warm air, using a well-ventilated oven at an appropriately controlled temperature.

"Waterproofing" Process

Absorbent materials, including "vulcanized fibre," low grades of phenolic resin materials such as mouldings, paper and fabric laminated tubes, sheets and rods, the synthetic resin bonded pressboards, and casein products, require waterproofing. Wax, shellac solutions and nitrocellulose base lacquers are used. Other synthetic resin lacquers and varnishes can be employed.

Wax in general is unsuitable and is not recommended. Its chief use is for plaster casts and for moulds from which the electroplate coating is to be stripped. Adhesion of plating on it is poor and in general relies upon the contour of the object being such that the metal deposit holds itself in position by its own mechanical strength.

Shellac and nitrocellulose solutions are both good, each having advantages and disadvantages. Shellac has the advantage of yielding solutions of higher total solids content than nitrocellulose, and therefore fewer coats are required to render a material relatively impervious. On the other hand, if nitrocellulose bronzing media are to be used as the conducting coats, these brush better over a nitrocellulose base than over a shellac coat. Spray application overcomes this difficulty, which can also be surmounted by applying an intermediate layer of boiled linseed oil, for example, in white spirit solution.

Table 33.—Laboratory Characteristics of High-grade Shellacs.

Sample No.	1	2	3	5	6
Type	Orange shellac powder	White lac (button)	White lac button)	Orange flake shellac	Lemon flake shellac
Loss % on heating to constant weight at 38 to 43°C.	1.4	1.3	1.7	1.1	1.4
Ash in incineration %	0.47	0.21	0.15	0.55	0.43
Iodine value (WIJS)	17.3	13.4	12.6	18.5	16.5
Alcohol insoluble matter %	2.1	0.5	Nil	2.0	1.9
Petroleum ether soluble matter (wax and resin) %	6.4	4.7	1.5	6.5	5.5
Acid value of pet. ether soluble, mgms.KOH/gm.	60.0	210	180	65.0	63.0

Table 34.—Laboratory Characteristics of Shellac Solutions.

Sample No.	1	2	3	4	5	6
Type	50% pale orange solution	40% white solution	40% pale orange solution	40% orange solution	30% brown solution	10% orange solution
Composition %:						
Shellac base	52.4	38.8	42.2	41.1	30.5	11.4
Spirit (64 O.P. industrial methylated)	47.6	61.2	57.8	58.9	69.5	88.6
	100.0	100.0	100.0	100.0	100.0	100.0
Quality of shellac base:						
Ash %	0.74	0.52	0.55	0.61	0.12	0.37
Petroleum ether soluble %	5.2	6.6	7.5	6.8	2.5	4.2
Acid value of pet. ether soluble, mgms. KOH/gm.	87.5	92	83	115	92	94
Iodine value	18.5	4.0	20.0	20.0	15.7	18.3

The shellac solutions can be prepared by dissolving a good grade of shellac in methylated spirit; pale orange flake shellac is the material commonly employed. It should be checked to ensure freedom from wax and rosin adulteration. High commercial grades are illustrated in Table 33. Alternatively, shellac solutions in various strengths are commercially available, as illustrated in Table 34. Again, these should be inspected for quality of shellac and quality of spirit. It is generally convenient to purchase a high concentration of shellac solution, e.g. 50 per cent. pale orange grade, and dilute with industrial methylated spirit of 64 OP strength to suit the needs of the job, that is, the film thickness or degree of penetration required, and whether applied by dipping, brushing or spraying.

The nitrocellulose solutions can be the normal colourless lacquers supplied for wood or metal finishing, or the bronze powder media. They can be appropriately diluted to suit the mode of application with cellulose thinners. A range of examples supplied from different sources to show contrast and comparison is given in Table 35. For very clear media giving exceedingly thin coatings that are continuous and highly resistant to moisture penetration, the cellulose/glyptal combination lacquers are perhaps most superior. Examples are given in Table 36.

Apart from these orthodox waterproofing media, it has been found quite convenient, if not more satisfactory, to employ air drying oil varnishes, of varieties common in industrial finishing shops. A very sound one is a good quality china wood oil or tung oil varnish. This can be adjusted in consistency with white spirit or solvent naphtha to enable it to be applied by dipping and draining,

dipping and whirling, by spray or by brush. Its surface dries quickly and is hard dry for handling in 24 hours. It can be force dried, for example, in 30 minutes at 250 degrees F. or in 2 hours at 200 degrees F. A closely similar material is an air temperature polymerizing phenolic resin varnish, which, except that solvent naphtha is used for thinning, is similar in application, etc., to the tung oil material. Commercial qualities are depicted by laboratory characteristics in Table 37. However, if cellulose media are selected for the next operation, these oil varnishes should definitely be oven dried, otherwise there is a strong tendency for them to craze or lift when the cellulose is applied.

It should always be remembered that these coatings are in themselves highly water resistant and it is thereby that they impart qualities of imperviousness to the base material. In other words, the properties of the base material are not changed in this respect, and absorption is delayed or retarded so long as the waterproofing coat is intact. Liberties should therefore not be taken and all subsequent immersion times should be minimized.

These waterproofing coats also serve as bonding coats for the conductive layer and hence for the electroplated deposit. For non-porous articles they are not required; many devices have been exploited for these.

The general procedure for non-porous plastics is to prepare the surface by a roughening process. Mechanical roughening is often convenient and is, in fact, the obvious choice. Abrasive blasting with sand or angular crushed-steel shot is an obvious choice. This can be used for phenolic and amino resin mouldings, as well as for boards and rods of this material. It can, of course, be applied to other products, shape and fragility being the chief limitations.

Grinding or milling operations may leave the surface sufficiently rough, sanding may be employed, or even pumice and water when convenient. The nature of the work is generally the determining factor.

Physical and chemical methods of roughening are also employed. Much work has been done in this direction during the past 10 years, and, in fact, they offer much promise for the future.

The physical methods are based upon the principle of "swelling" the surface of the work by means of suitable solvents or mixtures of solvents. The process is

Table 35.—Laboratory Characteristics of Clear Colourless Nitrocellulose Media.

Sample No.	1	2	3	4	5	6
Type	Metal lacquer	Metal lacquer	Metal lacquer	Spraying bronzing medium	Spraying bronzing medium	Brushing bronzing medium
Chemical:						
Volatile spirit (loss in weight % 3 hours at 110°C)	86.5	85.0	86.3	84.0	79.5	91.2
Total solids %	13.5	15.0	13.7	16.0	20.5	8.8
	100.0	100.0	100.0	100.0	100.0	100.0
Physical:						
Viscosity at 25°C., centipoises	1,100	350	800	100	95	250
Specific gravity at 25°C., centipoises	0.910	0.872	0.895	0.905	0.908	0.832
Dilution for spraying (lacquer/thinners)	50/50	Nil	67/33	100/0	100/0	—

Table 36.—Laboratory Characteristics of Clear Colourless Cellulose/Glyptal Synthetic Resin Combination Lacquers.

Sample No.	1	2
Chemical:		
Volatile spirit (loss in weight % 3 hours at 110°C.)	85.5	91.0
Total solids %	14.5	9.0
	100.0	100.0
Physical:		
Viscosity at 25°C., centipoises	1,000	13
Specific gravity at 25°C.	0.884	0.880

Note.—Dilute No. 1 50/50 by volume with thinners for spraying.

Table 37.—Laboratory Characteristics of Air-drying Varnishes, China Wood Oil and Air-polymerizing Phenolic Resin Types.

Sample No.	1	2	3	4
Type	China wood oil	China wood oil	Phenolic resin	Phenolic resin
Chemical:				
Volatile spirit (loss in weight %, 3 hours at 110°C.)	42.5	32.0	50.5	45.3
Total solids %	57.5	68.0	49.5	54.7
	100.0	100.0	100.0	100.0
Ash in incineration %	0.70	0.18	0.10	0.18
Physical:				
Viscosity at 25°C., centipoises	235	320	65	185
Specific gravity at 25°C.	0.905	0.914	0.907	0.915
Drying time, hours:				
Surface	2	2	5	3
Hard	8	4	6	4

somewhat akin to chemical or electrochemical etching of metals prior to electroplating. Rubber and hard rubber products such as ebonites can thus be roughened by immersion in solvents such as benzene, coal-tar naphthas, or acetone. Phenolic resin products respond to acetone. The thermoplastics can be treated in solvent, but this is usually too drastic, and a mixture of solvent and non-solvent is preferred. Acetone is a solvent for cellulose acetate, acetone or amyl acetate for nitrocellulose, benzene or naphtha for polystyrene, trichlorethylene or ethylene dichloride for acrylic resins. A suitable non-solvent is chosen from methylated spirit, coal-tar naphtha, petroleum, benzine or white spirit, etc.

In all these solvent methods of roughening, control must be exercised to avoid distortion, rounding of edges, or excessive solution. Temperature must be recorded, and time period closely controlled. The use of solvent/diluent mixtures greatly assists in practice, rendering the degree of control necessary less critical.

Several chemical methods of roughening have been employed. U.S. Patent No. 2063034 deals with the cellulose esters, and quotes the following formula for immersion treatment:—

Sulphuric acid of density 66 degrees Be	100 ml.
Potassium dichromate ...	15 gms.
Water	25-30 c.c.

Experience is required in judging the best immersion time, the work being withdrawn before actual attack occurs. It is then rinsed in water till free from chemicals.

Another chemical roughening agent is hydroquinone solution of 3 to 4 per cent. strength. It has been used for amino plastics, casein and glue or gelatin products, and is covered by U.S. patent No. 2214646.

The metal finishing shop bright acid dip (concentrated nitric and sulphuric acids, the mixture being used cold) has also been employed, the work being removed immediately noticeable attack commences. Water rinsing, a weak alkali dip (e.g., 5 per cent. sodium carbonate) and further water washing, follow.

Work subjected to these chemical or physical roughening pre-treatments is then immediately ready to receive the conductive coat, silver immersion being generally selected, and then electroplating follows, usually with copper.

Conducting Coats

The conducting coats are provided by graphite, fine metal "bronze" powders, either copper or brass, chemically reduced silver and silver sulphide, the latter itself being conducting.

The most convenient form in which to apply the graphite is one of the colloidal "dag" products. The water solution "aqua-dag" is best known. It may be

applied by dipping, brushing or spraying. The more recently introduced mixtures such as acetone "dag" and varnish "dag" have advantages. With some plastics, e.g., phenolics, the acetone "dag" can simultaneously roughen and provide the conducting coat; with others, e.g., cellulose acetate, a diluent such as methylated spirits should be present if dip methods are employed.

While the organic solvent-colloidal graphite mixtures are the preferred graphite media for plastics, aqueous mixtures are also used. Two pounds of electrotyper's graphite per gallon of water may be taken as a guide for the spraying of adherent coatings. Nevertheless, the colloidal graphites are advantageous even when water media are employed. The modern tendency, therefore, is to use "aqua-dag," diluting with water and incorporating a little gelatine and potassium dichromate. These ingredients improve adhesion and enhance water resistance. A nominal composition is as under:—

Colloidal graphite	4.5% by wt.
Gelatine	0.25% by wt.
Potassium dichromate	0.0025% by wt.

One or more coats can be applied as required, dip, spray or brush application used according to the nature of the job, and, in some instances, mechanical rubbing into the pores or light mopping to spread the coating is resorted to, particularly on large objects or complicated shapes.

In "Plastics," February, 1943, p. 63, reference is made to the work carried out by Messrs. Acheson, Ltd., on graphite conducting films as a basis for the electroplating of plastics as well as other non-metallic materials. Their procedure is to first apply a solution of glue containing potassium dichromate and allow to dry. The film is actinically hardening and is particularly desirable on rough surfaces because it presents a smooth surface upon which to apply the graphite solution and thus gives best conditions for the orientation of the flat, plate-like graphite particles. By burnishing the dry graphite coatings, best electrical conductivity values may be obtained, and values of the order of 20 to 30 ohms/inch square are practicable.

The bronze lacquers are more usually employed as the conductive ground coat. A representative composition is as follows:—

Nitrocellulose bronzing medium	1 pt.
Nitrocellulose thinnings ...	1 gal.
Copper powder	3½ lb.

Each of these ingredients was discussed in detail in an earlier section of this article and it is only necessary to point out that this composition is high in metal content and low in binder. One technique of application is to apply two coats by spray, "misting" it on so that the film dries as rapidly as deposited, in contrast with flooding-on a wet coat. After fully drying for a couple of hours, the work is plated in an acid copper sulphate bath. Several wire connections are taken to the work to assist in current distribution and to permit as high a current density as possible being employed. When a thick copper coating is deposited, the usual single wire suspension used in metal plating may be employed, any other metal deposit may be plated over the copper, e.g., nickel, chromium, etc., and polishing or colouring may be performed. Alternatively to the copper plating, a chemical silver deposit as detailed below may be applied, followed by plating from any desired plating solution.

Wide variations from the above bronze powder lacquer formula, of course, are used. One American practice is to spray a tin powder mixture for the first coat so as to ensure by visual observation that complete coverage is secured with the second coat. A tin lacquer of the following concentration is used:—

Tin powder	2 lb.
Cellulose bronzing medium ...	1 gal.
Cellulose thinners	1 gal.

An air drying time of an hour is allowed before spraying the following composition for the bronze coat:—

Copper powder	2 lb.
Cellulose bronzing medium	2-3 gal.
Cellulose thinners	1 gal.

This is then allowed to dry for three to four hours before electroplating.

Some platers specify a maximum gum content of 5 per cent. in the lacquer and insist on the metal powder being grease-free, degreasing prior to use if necessary. The reduced copper powders dealt with in an earlier instalment of this article can also be used.

The silvering dip referred to above is advantageous. Immersion need only be for a few seconds, the solution containing a silver salt and a reducing agent. No current is employed. A typical composition is as under:—

Water	1 gal.
Silver nitrate crystals ...	3 oz.
Sodium cyanide	3½ oz.

Any cloudiness that develops in the solution in use is cleared by the addition of further sodium cyanide, but excess must be avoided.

An alternative silvering solution contains alcohol as reducing agent, viz.:—

Water	1 gal.
Silver nitrate crystals ...	7½ lb.
Ammonia (S.G. 0.880) ...	5 lb.
Methylated spirit, 64 O.P. ...	1¼ gal.

The silvering operation not only improves upon the electrical conductivity but also serves to show up any spots or areas not properly covered with a metallic copper layer. Any such spots on large surfaces can be touched up with bronze lacquer by brush, while small articles can be rejected for stripping and retreatment.

Silver is applied as the conducting layer from one of several processes, and is applied directly to plastics, to lacquered surfaces, or to the copper-bronzed coatings. One process uses two solutions, one containing the silver and the other being the reducing agent that achieves the deposition of the metallic silver on the work. The solutions are prepared as follow:—

Silver Solution

Dissolve 10 gms. potassium hydroxide in 200 ml. distilled water.

Dissolve 20 gms. of silver nitrate crystals in 200 ml. of distilled water.

Mix these two solutions and add ammonia until the precipitate of silver hydroxide just redissolves.

Finally add silver nitrate from a 5 to 10 per cent. solution until the precipitate just reforms and persists, and the solution darkens permanently.

Reducing Solution

Dissolve 90 gms. of sugar in 1 litre of water, add 4 ml. of concentrated nitric acid (S.G. 1.42), boil for five minutes and then allow to cool.

If it is intended to keep the solution, 175 ml. of alcohol (64 O.P. methylated spirit is satisfactory) is added.

Formaldehyde or rochelle salts solutions are also used as reducing agents.

The silver and reducing solutions are used in proportions four to 1 by volume. They may be mixed immediately prior to use, or they may be applied separately to the article by dip or spray. In America, spray equipment has been specially designed for this application, and used successfully for application of these silvering solutions to plastics prior to plating.

One equipment embodies a two-nozzle spray arrangement. The silver solution is atomized from one jet and the reducer from the other. A hydrazine reducer, e.g., a solution of hydrazine sulphate, is employed. The two atomized solutions converge and mix just before reaching the object to be coated.

In another equipment, the two solutions are mixed in a specially designed chamber attachment immediately before required, and are fed to a single nozzle.

When the silver coating has formed, the work is rinsed in water and plated in a copper-sulphate solution containing about 2 oz. of sulphuric acid/gal.

Phenol-formaldehyde resin products containing a little free formaldehyde are often silvered from a silvering solution by immersion, the formaldehyde in the material itself serving as reducer. For example, the following mixture is used:—

Water	1 gal.
Ammonia (S.G. 0.88)	Approx. ¼ pint
Silver oxide	1 oz.

The quantity of ammonia used must be sufficient to clear the solution. Work is immersed in this solution and boiled for about 30 mins. It is then removed, rinsed in water, and allowed to dry for three to four hours. Any surplus silver oxide is then removed by brushing or other suitable means. It can then be electroplated in an acid copper sulphate solution of low acidity or in a cyanide silver bath.

Silver sulphide, which is a conductor, is employed in conjunction with shellac. It can be incorporated in the shellac solution used for coating the material. Alternatively, after shellacing the surface in the normal manner, the work is immersed in an alcoholic solution of silver nitrate. This causes the silver salt to penetrate. The work is then dried and exposed in an atmosphere of hydrogen sulphide until a uniform film of black silver sulphide is produced. It is then rinsed in water and plated directly with copper from an acid copper sulphate bath.

The shellac-silver solution can be prepared from 1 oz. of silver nitrate crystals and 4 oz. of flake orange shellac in 1 gallon of alcohol or 64 O.P. methylated spirit. For porous material, a normal shellac coating should be first applied. In fact, it is probably best to apply a thin shellac ground coat in all cases.

The alcoholic silver solution for immersion treatment can have the following composition:—

64 O.P. methylated spirit	1 gal.
Water	½ gal.
Silver nitrate crystals ...	1 lb.

Information appertaining to these silvering processes is given in the U.S. Bureau of Standards Circular No. 389 (1931).

Early Silver Immersion Process

The Technical Supplement of "Frankfurter Zeitung," August 24, 1933, refers to the early introduction of the silver immersion coating process as applied to numerous non-metallic materials, viz., wood, paper, textiles, leather, asbestos, vegetable and synthetic fibres, cellulose including cellulose films, rubber, casein plastics, synthetic resins and synthetic resin-bonded products, rubber, ebonite, etc. The coating produced is, by this German process, thin but electrically conductive and can be thickened by subsequent electroplating. Many of the advantages of the process are pointed out to stress its rightful application rather than claiming it to substitute direct metallization by, for example, metal spray with the wire pistol. Thus, it may be necessary to metallize articles of high polish or low porosity, and roughening to promote adhesion may be inadmissible; or again articles may be too fragile to roughen and therefore metal spray is out of the question. In other instances, it may be necessary to metallize internal surfaces that are too deep or too awkward to be accessible in the metal-spray process. The German article claims silvering to give a homogeneous and adherent layer. Details of the process are not given, but its nature can be estimated from an example, and its relationship to the known "swelling" and silvering processes assessed.

Cellulose esters and ethers (e.g. cellulose acetate or ethyl cellulose) in film form are first immersion treated in a reducing bath which has the dual function of "roughening" for adhesion and applying a layer of reducing agent. The balance of solvents is selected to give the desired degree of "opening" of the surface without undue dissolution or softening, and the nature of the reducing agent is such that no decomposition (as, for example, by saponification) occurs, but a residual film of the agent is left uniformly over the surface. Solutions of the cellulose derivatives themselves can form the media for these reducing agents. The next treatment, after drying, is immersion in the silvering bath, which comprises the silver and reducing mixture. Rubber articles such as those used in production of artificial dentures, are treated by this process, and in this case the reducing agents for the first operation can be one of the di- or tri-hydric phenols.

A number of applications for the German process are claimed. Electrical condensers for radio and telephonic

apparatus, for low and high-tension work, represent one of the most important. The favourable dielectric constant of cellulose acetate, and power loss value of polystyrene at high frequencies, make the process attractive for these materials. No gas, gaps or voids between metal and dielectric is a condition ensured, one that is not achieved when using separate films of dielectric and metal foil merely physically positioned. Another application claimed is for aircraft wings and airship fabrics. Wing-covering materials doped with nitrocellulose medium and coated with cellulose acetate lacquer, if treated by the silvering process, are resistant to deterioration by ultra violet light and, further, the silver coating has good heat-transfer properties, promoting temperature uniformity and thereby minimizing the development of static charges. Such treatments are said to give superior results to those derived from the use of aluminium powder coatings applied from cellulose media. Again, the treatment of aeroplane propellers is claimed to provide them with increased resistance to atmospheric conditions. The silver coatings are in intimate contact with the base wood, which may, of course, be bakelized wood, free from air bubbles and therefore very adherent and protective, even though the average thickness of silver is only of the order of one mil or less. Further, light rubbing imparts smoothness and high polish.

(To be continued.)

PLASTICS IN BUILDING

AT a recent lecture before the Incorporated Association of Architects and Surveyors, in London, Mr. H. H. Lusty, of Bakelite, Ltd., pointed out some of the exaggerated views on the possibilities of plastics and stressed the danger in overrating them, especially since their real and possible uses are so valuable and varied. " It is not pretended," he said, " that plastics can seriously take the place of brick, concrete, steel or even timber in the main structural parts of a building; although in the newest combinations with plywood they closely approximate the latter for some purposes and are often far superior. Generally, however, their main applications are in the form of fixtures and accessories.

" For windows and frames, although it is unlikely that plastics will be able to compete with metal in common casement frames, it should be possible to design special types for which plastics, such as the good-weathering darker phenolics, could be used; or, after the war, the lighter-coloured melamine resins, which also have good weathering properties. In place of glass itself, the methyl methacrylates have better light-transmitting properties and are tougher than glass, but somewhat more expensive. They are well adapted where curved transparencies are wanted, and an outstanding example of their use is in aircraft enclosures.

" Moulded wall tiles have been made in America from polystyrene, the most water-resistant plastic. The tiles are lighter in weight than ordinary ceramics, and can be produced in a large range of colours like tinted glass. They may be at present rather more expensive, but with the vastly increased output of styrene for making synthetic rubber, their cost might be reduced to economic levels. Both wall and floor tiles could be made from vinyl resin compounds, of varying degrees of hardness and elasticity.

" Plumbing requirements are rather more exacting, especially where boiling water or corrosive wastes have to be handled. Most of the requirements in this field could probably be met by at least one of the newer thermoplastic materials, which is about one-quarter the weight of iron piping and can withstand frost effects; but it has a relatively low softening point and would not stand up well to boiling water.

" Plastics could probably be satisfactorily used for lavatory cisterns, but further experience is needed on this point. Also washbasins, sinks and baths could be moulded.

" It is probably in the direction of interior decoration that plastics can find greatest scope, especially the new laminated type, used as thin veneers on plywood, or as solid wall panels, etc. Here the new materials offer many advantages."

Serviceability of Plastic Gears

Static and Dynamic Strength and Wear Resistance of Representative Types of Laminated Plastics for Gears have been Studied by Opitz and Reese ("Kunststoffe," 1942/32/263) and Ulrich and Muller ("Kunststoffe," 1942/32/270). Simultaneously, Plastic-bonded Laminated Wood for the Same Purpose was Also Studied. Tests were Carried out on Involute Gears under Conditions Simulating Those Occurring in Practice

TESTS carried out recently on laminated materials, designed to ascertain their suitability for manufacture of gears and their wear resistance in this regard, have provided interesting results. In Table 1 are recorded the structure and composition of the materials used and the gear types investigated. Table 2 records some data upon the laminated-wood gears. In all 21 types of gear were tested.

Static Bend Tests

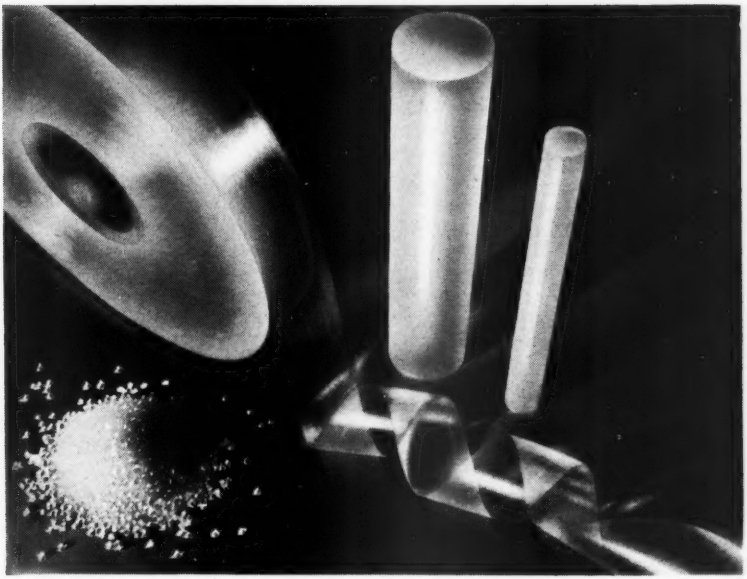
Fig. 1 shows the arrangement of apparatus for static bend tests. The gear (a) to be tested is placed on a pivot (b), between two clamping plates (c). Rotation of the gear is prevented by means of the bolt (e) and clamping screws ($e_1 - e_4$). The gear so mounted is then placed in a testing machine, a force (P) is exerted by means of a form plate (f). In order that the lever arm of the force (P) is equal for teeth of the same pitch, grooves (g) are milled into the flanks of the teeth, into which a pin (h) is inserted and against which the form plate (f) presses.

Table 1.—Materials Investigated

Manufacturer	Type of material	Code	Description of gear			Chemical Composition	Resin content per cent.	Manufacturing pressure. kg/cm²	Structure
			Mod.=3 65 teeth	Mod.=5 39 teeth	Mod.=7 28 teeth				
A	Coarse laminated textile	Hg/A	I 7	I 15	I 24	Cotton fabric with 20% cellulose fibre; phenolic or cresylic resin bond	40	100	16 sheets per cm. fibres at 90°
B	Coarse laminated textile	Hg/B	II 5 II 32	II 10 II 37	II 15 II 42	do.	50	70	do.
B	Fine laminated textile ..	Hf/B	III 10 III 11	III 21 III 22	III 32 III 33	do.	50	70	30 sheets per cm. fibres at 90°
C	Compressed laminated wood	PH/C	IV 10 IV 34	IV 20 IV 35	IV 30 IV 36	Beech veneers with Tego film	4.2	200	10veneers per cm. grain at 45°

BEECH LAMINATE WITH TEGO FILM

Manufacturing pressure per kg/cm²	200		300		400	
Veneer thickness mm.	0.3	1.0	0.3	1.0	0.3	1.0
Grain angle for successive veneers 15°, 45° and 90°						



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The stress tooth during test was always in the position shown in Fig. 1. The teeth of every gear were numbered from 1 onwards. Results are summarized in Table 3. Fig. 2 represents the average values of the breaking loads of the teeth in the different series of tests, thus permitting comparison with respect to origin and pitch.

For all pitches, the coarse laminated textile material (HG) gives the lowest values and the compressed wood (PH) the highest values. Values for coarse laminated textile material originating from two different producers were found to be in agreement. Variation in values for different teeth on the same gears occurred to only a slight extent and no regular cause could be ascertained for this.

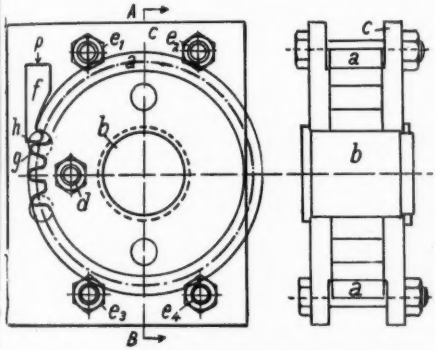

Fig. 1.—Clamping device for testing gear teeth in static bend: a, gear tooth; b, stop; c, clamping plate; d, bolts; e_1, e_4, clamping screws; f, nose for application of load; g, groove in tooth flank; h, pressure pin; P, direction of applied load.

In the design of gears bending stress is usually calculated by means of the formula $S_B = \frac{P \times a}{W}$ where S_B = bending stress, P = the static load acting on the tooth and a = the distance between the point of action P and the bottom of the tooth. W = section modulus of the tooth rod. Bending strengths calculated according to this formula are given in Table 5. They show again that gears of coarse laminated textile material (HG) have the lowest strength; materials from producers A and B giving equal readings. Gears of the finer laminated textile material gave somewhat higher values, whilst compressed-wood gears were still better.

Dynamic Bend Tests

Test arrangements are shown in Fig. 3; the force (B) is transmitted from the Mohr and Federhaff machine to the teeth by means of form plates (D_1 and D_2). In this case also pins (s_1 and s_2) are provided between the plate and the tooth flank bolts (B), and links (L) serve only to catch the wheel when a tooth breaks, and are not connected rigidly with the clamping head (E).

A stress frequency of 750 per minute was employed and tests were carried out with one of each gear type in each type of material. Only the course of the S/N curve was determined, sometimes with reference to two points only. Stress cycles up to 10×10^6 were used. The gears not breaking under this number of reversals being recorded in Table 3.

Bending stresses $S = \frac{P' \times a}{W}$ resulted from the application of loads P′ have been calculated in order to serve as comparisons of dynamic bend strengths. These values show little difference for metric moduli of 5 and 7 in the case of the laminated textile wheels, but values for compressed and laminated wood are considerably higher. For gears of metric modulus 3, comparative dynamic bend strength is somewhat lower, pointing to an influence of the structure of the material on account of the smaller dimensions of the teeth. The accuracy of these values, however, is somewhat reduced by the relatively wide range of the forces measured (440-770 lb.), this being at the lower limit of the useful load of the testing machine. Surface finish of the teeth may also have an important influence where dimensions are smaller.

Impact Bend Strength

The gear is held as for the static tests, being clamped between two plates

fixed in a frame of the testing machine. The hammer has its striking face curved to correspond to a tooth so that, at the moment of impact, conditions are similar to two gears contacting on the pitch line with respect to two teeth. Test results are presented in Table 4 and are shown graphically in Fig. 5. Impact bend strength is calculated as the quotient of work impact and cross-sectional area at the tooth root.

In the case of the laminated textile materials average values vary between 17 and 31 cm.kg./cm². Variations are due more to changes in the metric modulus of the teeth than to differences in the material. Compressed laminated wood surpasses in impact bending strength the laminated textile materials by about 1½ times for metric moduli of 3 and 5. In the case of modulus 7, much higher values have been obtained.

A definite relationship between the position of the teeth relative to the wheel body and variation in the results were not found. Table 5 presents a summary of all test results. Incidentally, although this test is made to simulate the effect of impact between gear teeth in actual contact on the pitch line, the greater radius of the lever on the testing machine really negates this similarity.

Wear Tests

Wear tests were carried out to determine (1) possibility of improving various types of plastic employed for gears; (2) to assist in the formulation of recom-

Table 2.—Results of Static Bend Tests

Material	Gear No.	Tooth No.	Breaking Load kg.	Mean Breaking Load kg.
		Modulus = 7. 28 teeth		
Hg/A	I 24	2	1980	
		4	1480	1783
		9	1930	
		11	1740	
Hg/B	II 15	1	1740	
		3	1720	1708
		8	1730	
		10	1640	
Hf/B	III 32	1	2140	
		3	2050	
		8	2080	2073
		10	1890	
		15	2090	
		17	2150	
PH/C	IV 30	1	2385	
		2	2670	
		4	2460	
		9	2450	2503
		11	2435	
		23	2670	
		25	2450	
		Modulus = 5. 39 teeth		
Hg/A	I 15	1	1420	
		4	1410	
		10	1450	1378
		13	1290	
		20	1430	
		23	1270	
Hg/B	II 10	1	1370	
		4	1330	1339
		10	1325	
		13	1320	
	II 37	1	1400	
		4	1270	1345
		31	1400	
		34	1310	

Material	Gear No.	Tooth No.	Breaking Load kg.	Mean Breaking Load kg.
		Modulus = 5. 39 teeth		
Hf/B	III 21	2	2080	
		5	1420	
		6	1850	
		7	1670	1710
		10	1650	
		13	1650	
		31	1650	
	III 22	13	1610	
		23	1640	1573
		30	1470	
PH/C	IV 20	1	1830	
		20	1890	1843
		30	1810	
	IV 35	2	1755	
		11	1650	1680
		31	1635	
		Modulus = 3. 65 teeth		
Hg/A	I 7	7	785	
		12	820	
		25	870	
		30	730	813
		43	850	
		48	850	
		55	860	
		60	740	
Hg/B	II 15	7	880	
		12	880	886
		55	870	
		60	915	
Hf/B	III 11	7	945	
		12	940	941
		55	940	
		60	940	
PH/C	IV 34	7	970	
		12	970	
		25	1100	
		30	1070	1030
		43	1060	
		48	920	
		55	1050	
		60	1090	

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mendations for the use of these materials in the construction of gears; (3) to clarify effect of tooth design.

The following problems had to be solved: (a) Effect of veneer thickness; angular displacement of grain in consecutive layers; pressure on compressed laminated wood. (b) Difference in behaviour between fine and coarse laminated textile materials. (c) Difference between laminated materials of the same type produced by different manufacturers. (d) Behaviour of different materials under various running conditions. (e) Influence of number of teeth, modulus and length of contact (see Table 1) on the running properties of laminated plastic gears.

The materials listed in Table 1 and Table 2 were used for the wear tests, the mating gear being of cast iron. Lubrication was by means of calcium-soap grease supplied by the Vakuum-Oel-Gesellschaft. Test sets were designed in which four laminated plastic gears and two cast-iron gears were built in a gearbox and loaded by two torsion springs, the function of the driving motor being to supply frictional capacity only. Power is preferably supplied to the two cast-iron wheels (I and II) situated in the centre of the box (Fig. 6).

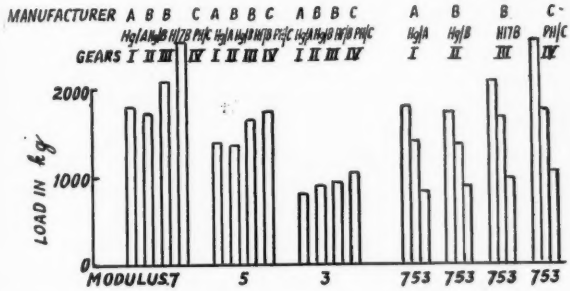
MANUFACTURER A B B C A B B C A B B C
GEARS I II III IV I II III IV I II III IV
2000
1000
0
LOAD IN kg
MODULUS 7 5 3
A B B C
I II III IV
753 753 753 753

Fig. 2.—Graphical presentation of results of static bend tests compiled from mean values presented in Table 2. (For key to materials, composition, etc., see Table 1.)

The non-homogeneous nature of the non-metallic gears rendered the technique of measure wear somewhat difficult. The simple weighing method was found unsuitable. A special instrument was, therefore, developed for measuring the thickness of the teeth, and the involute was measured by an involute tester.

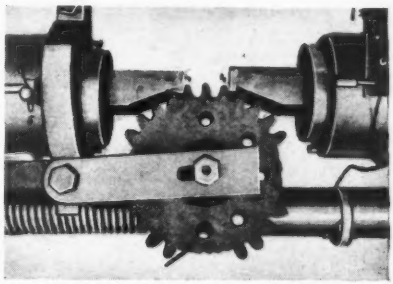

Fig. 3.—Assembly for alternating bend test.

Experience has shown that the wear process in a pair of gears is influenced by the following factors: (1) pitch-line velocity; (2) type and degree of loading;

Table 3.—Results of Alternating Bend Tests

Material	No. of wheel	Dynamic bend strength kg. for 10×10^6 reversals	Dynamic bend for 10×10^6	Stress kg/cm² reversals
Modulus = 7. 28 teeth				
Hg/A	I 24	500	375	—
Hg/B	II 42	550	412	—
Hf/B	III 33	550	412	—
PH/C	IV 36	1,200	900	—
Modulus = 5. 39 teeth				
Hg/A	I 15	400	400	—
Hg/B	II 10	400	400	—
Hf/B	III 21	400	400	—
PH/C	IV 35	800	800	—
Modulus = 3. 65 teeth				
Hg/A	I 7	250	412	—
Hg/B	II 5	200	332	—
Hf/B	III 11	200	332	—
PH/C	IV 34	350	584	—

(3) number of teeth modulus and length of contact; (4) surface finish of the tooth flanks.

In order that tests should correspond as closely as possible with service conditions, it was decided to select high and low tooth-load values and to run at high and low speeds, as shown in Table 6. The gears were of the same design as in Table 1 and the number of teeth in the meshing cast-iron gears was greater by one tooth than that of the laminated wheel, in order to ensure that new teeth always came into contact. Lubrication was supplied to the tooth flanks at intervals of 24 hours. During the course of the tests some 30,000 measurements had to be made, and this gave rise to some difficulties.

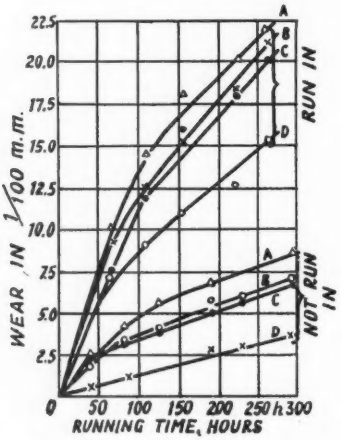

Fig. 4.—Wear curves for laminated wood gear teeth operating against mating gears in the "run-in" and the "not-run-in" condition: load = 30 kg./cm. of tooth width; peripheral speed $\frac{1}{2}$ 9 m/s.; modulus = 3, 65 teeth (grease lubrication). In manufacture, this material was compressed under a load of 200 kg./sq.cm. Curves A — 0.3 mm. veneers superimposed at 45°; curves B — 1 mm. veneers superimposed at 45°; curves C — 1 mm. veneers superimposed at 15°; curves D — 0.3 mm. veneers superimposed at 15°.

Measured wear is usually represented in

Table 4.—Impact Test Results.

Material	Gear No.	Tooth No.	Impact strength cmkg/cm²	Impact strength mean value cmkg cm²
		Modulus = 7. 28 teeth		
Hg A	I 24	1	31	
		6	32	
		8	31	31
		27	32	
		29	30	
Hg B	II 42	11	29	
		13	27	26
		18	24	
		20	25	
Hf B	III 32	11	31	
		13	24	27
		18	24	
		20	27	
PH C	IV 36	2	96	
		12	69	
		14	142	
		16	161	100
		18	55	
		23	120	
		25	58	
		Modulus = 5. 39 teeth		
Hg A	I 15	5	24	
		32	34	27
		34	27	
		36	23	
Hg B	II 37	3	22	
		5	25	
		11	21	23
		13	24	
		15	25	
Hf B	III 22	7	21	
		9	19	19
		12	17	
		37	19	
PH C	IV 35	10	38	
		15	38	38
		29	38	
		39	38	
		Modulus = 3. 65 teeth		
Hg A	I 7	8	30	
		11	21	
		14	22	23
		17	17	
		28	23	
Hg B	II 5	8	16	
		23	20	19
		30	18	
		37	23	
Hf B	III 11	15	18	
		18	13	
		26	18	17
		29	18	
		32	16	
		35	17	
PH C	IV 34	8	52	
		11	23	
		14	23	30
		17	26	
		26	31	
		29	26	

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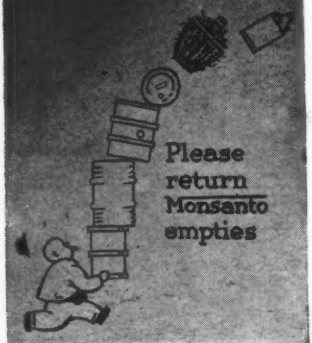

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relationship to running time, and curves obtained in this way are, in general, characterized by the fact that they rise quickly at the beginning of the test, but, after a given running time, continue at a constant angle (Fig. 4). Severe wear at the commencement of the test can be attributed to the running-in process, the remainder of the wear curve being proportional to running time. It is the latter portion of the curve which is used for fixing wear factors for the various materials examined under given test conditions.

In order to obtain simple comparative values, the wear factor was fixed for a running time of 50 hours. The extent and duration of the running-in time are dependent upon various influences, in particular, on the surface finish of the tooth flanks themselves. When two wheels have not been run in, grooves in the gear flanks of the counter wheels (these grooves arising during machining) act in an abrasive manner and increase wear.

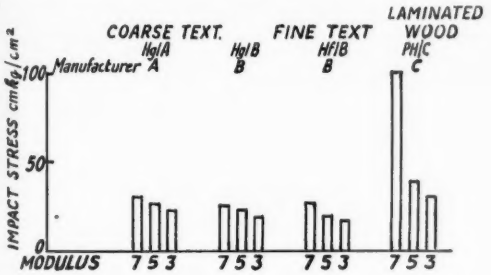
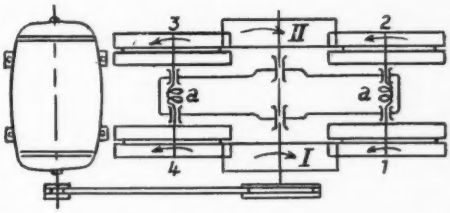


Fig. 5—Graphical presentation of results of impact bend tests compiled from mean values in Table 4. (For key to materials, composition, etc., see Table 1.)

Fig. 6.—Apparatus for testing gear under continuous running load: 1-4—plastic gears; I, II, cast-iron mating wheels; A—torsion loading spring.



Laminated Beech

Tests with this material were carried out at speeds of 890 and 1,780 ft./min. with loads of 168 and 280 lb./in. width. A good wear factor was obtained when the grain of successive veneers crossed at

Table 5.—Tabular Summary of Static and Dynamic Tests.

Manufacturer	Material	Modulus	Static Bend Strength kg/cm²	Dynamic Bend Strength kg/cm²	Impact Strength cmkg/cm²
1	2	3	4	5	6
A	Hg/A	7	1,338	375	31
		5	1,378	400	27
		3	1,355	412	23
B	Hg/B	7	1,378	412	26
		5	1,342	400	23
		3	1,376	332	19
B	Hf/B	7	1,554	412	27
		5	1,642	400	19
		3	1,569	332	17
C	PH/C	7	1,878	900	100
		5	1,762	800	38
		3	1,716	584	30

Table 6.—Circumferential Load and Pitch-line Velocity for the Wear Tests.

Circumferential load in lb. per in. of width of tooth	82.5			168			280		
Pitch-line velocity in ft. /min.	890	1,780	2,370	890	1,780	2,370	351	890	1,780

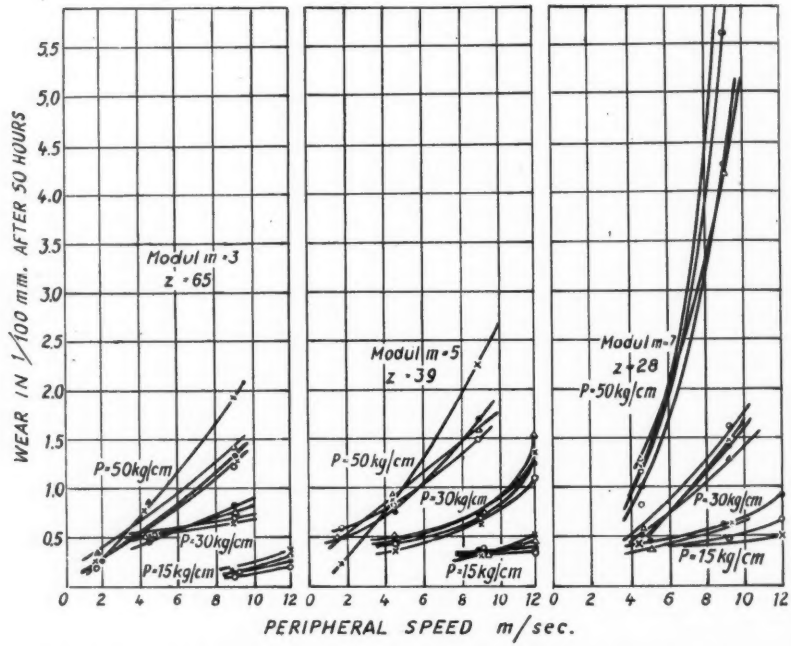


Fig. 7.—Tooth flank wear in relationship to speed of revolution for gears of modulus 3, 5 and 7, with 65, 39 and 28 teeth respectively (grease lubrication). P = peripheral loading on gear in kilograms per cm. of tooth width. (Curves may be identified as to material type by reference to Table 5.)

an angle of 45 degrees and when the veneer was 0.04 in. in thickness. The use of finer veneers, and thus an increase in the resin content, did not appear to reduce the wear of this wood laminate. Compression during manufacture above 2,840 lb./sq. in. also did not seem to improve wearing qualities.

Comparison Between Laminated Textile and Laminated Wood Material

Speed is an important factor in wear (Fig. 7). At low loads, wear increases only slowly with speed. With increased load, the curves show a steeper inclination. The same phenomenon is observed with gears of greater metric modulus. In the lower and medium range of loads, practically no difference between the various laminated materials is to be observed. Only at higher loads and speeds do coarse laminated textile materials exhibit a less favourable load factor.

(Continued on page 577)

PRODUCTION NEWS

Raw Materials, New Plant, Works Organization, Control Apparatus, Research, Personal and Trade Notes

STEAM JET COMPRESSORS.—For many special applications in the chemical and allied industries, including, for example, the compression of air or any other gas, the use of the steam jet is a simple and convenient method, which is also cheap and requires little space. In this connection much interest attaches to the steam jet compressor made by Meldrums, Ltd., Timperley, near Manchester, available in twelve standard sizes having a capacity from 1,000 cubic ft. (as free air) per hour, using a ½-in. steam pipe, to 61,000 cubic ft. per hour, with a 4-in. steam pipe. Corresponding figures for the air admission pipe are 1 in. for the smallest size and up to 8 ins. for the largest size, and these figures, given as typical, apply to the conditions of 50 lb. per sq. in. pressure in the steam supply and for a water pressure of 8 ft. head with an air pressure an eighth of the steam pressure. Under more favourable conditions, such as higher steam pressure and lower air pressure, smaller pipes can be used for the same duty, or alternatively the duty is increased.

One of the big advantages of using steam jet equipment of this kind for compressing air or gases is that, as already indicated, it is much cheaper than any other method, since there are no moving parts.

Some typical applications are aeration, oxidation, and bleaching of oils and other liquids, as well as the manufacture of a solution of soluble gas in water, such as sulphurous acid and carbon dioxide. Also the agitation of liquids by blowing in air or gas through a perforated pipe or by means of a false bottom, as well as the collection and discharge under pressure of exhaust steam, such as when used for evaporating. Further, this method is valuable for the scrubbing, general cleaning, and cooling of gases by forcing them through water or any other liquid, and another example that may be mentioned is the precipitating of calcium carbonate in the softening of water with lime and soda ash. Again important is the application for producer gas plant, that is blowing into the fuel bed a mixture of air and steam or water vapour to gasify the solid fuel.

No foundations are necessary, and the apparatus may be fixed in any pipe line, irrespective of whether it is vertical, inclined, or horizontal. No auxiliaries are required.

AUXILIARY GAS FIRING.—In some cases it is a good proposition for smaller industrial establishments, but depending, of course, on the local conditions, to use auxiliary gas firing, with, say, town gas or producer gas for the operation of steam boilers.

In this connection notable work is being carried out by Liptak Furnace Arches, Ltd., of London (68, Victoria Street, S.W.1), using one or other of the wide range of their "Gako" low-pressure turbulent burners. These are just as suitable for small volumes of any combustible gas for the operation of cylindrical boilers as they are for large water-tube boilers, whether for gas firing only or in conjunction with solid fuel.

One general design of these burners in the case of "Lancashire" and other cylindrical boilers is on the saddle-shape principle with natural draught, being fixed to the top of the furnace tubes of the boiler above the doors used for hand firing, which is carried on as usual.

STANDARD FOR SYNTHETIC-RESIN BONDED-PAPER SHEETS.—For some years there have been two separate specifications for synthetic-resin bonded-paper sheets for electrical purposes, namely, B.S. 316 and B.S. 547. These two specifications have now been amalgamated and superseded by B.S. 1137, which has just been issued by the British Standards Institution.

This new specification relates to sheets for use as electrical insulation at power frequencies, and it should be noted that separate proposals are in preparation for a revised specification for synthetic-resin bonded-paper tubes. In the meantime B.S. 316-1929 is still applicable to tubes.

The specification is based on technical data supplied by the Electrical Research Association, and with a view to reducing to a minimum the amount of testing required the specification has been divided into

mandatory and optional clauses, the former being limited to the tests necessary for the rejection of inferior material.

Copies of this specification (B.S. 1137-1943) may be obtained from the Publications Department, British Standards Institution, 28, Victoria Street, London, S.W.1, price 2s. post free.

LONDON SHELLAC RESEARCH BUREAU announces that although the Indian Lac Cess Committee has recently abolished the post of Special Officer Lac Inquiry, which was held by Mr. A. J. Gibson, F.C.H., F.L.S., and has reorganized the Bureau under the Acting Directorship of Dr. B. S. Gidvani, F.I.C., A.M.I.Chem.E., its policy remains unaltered.

The Bureau and its Laboratory will continue to render all possible assistance to the shellac-consuming industries as in the past. All confidences placed in the Bureau will be respected, and secrecy in regard to any processes revealed to it maintained. The sole object of the Bureau still remains the same, namely, to improve the existing uses and find further uses for lac, and the Lac Research Laboratory will continue to carry out research work with this object in view.

The Bureau extends its co-operation to the Shellac Trade and industries, and trusts that there will be a reciprocal response. Free technical service and advice on problems connected with shellac will be available as heretofore.

All inquiries in future may be addressed to:—Dr. B. S. Gidvani, Acting Director, London Shellac Research Bureau, 79, Grassmarket, Edinburgh, 1.

WAR RISKS INSURANCE.—The Board of Trade have, with the approval of the Treasury, decided that in respect of the period beginning December 3, 1943, and ending March 2, 1944, the rate of premium payable under any policy under the Commodity Insurance Scheme shall be at the rate of 5s. per cent. for three months (or 1s. 8d. per cent. per month). The new rate is a reduction of one-third on the rate for the current period.

INDUSTRIAL FIRE BRIGADES.—The Eastern Regional Competition for Industrial Fire Brigades was won by a team from B.X. Plastics, Ltd., with a time of 4 mins. 16⅕ secs., 7 secs. ahead of the nearest competitor. The competition consisted of various drills with stirrup pumps and trailer pumps. The head of the Fire Brigade in question is Mr. G. W. Tice, who has just been made a Senior Company Officer in the National Fire Service, and his deputies are Mr. A. J. Tonkin and Mr. R. Hutchins, both of whom have been made Company Officers.

SOCIETY MEETINGS, Etc.

Institute of the Plastics Industry.—The activities of the Southern Section for November and December are as follow:—

(1) A course of lectures has been started at the Municipal College, Portsmouth (on Plastics Technology), each Monday evening, 6.30 to 8.30 p.m. Mr. G. L. Barron, A.I.R.I.(Sc.) (Hon. Secretary to the Southern Section), is the lecturer.

(2) The next technical meeting will be held on Wednesday, December 15, 1943, at the Polygon Hotel, Southampton, when Mr. S. R. Devlin (Managing Director of Catalin, Ltd.) will talk on "Cast Resins."

The Scottish Section of the Institute will meet on December 11 at the Royal Technical College, Glasgow, when Mr. Foster Sproxton will deliver a lecture entitled "Nitrocellulose."

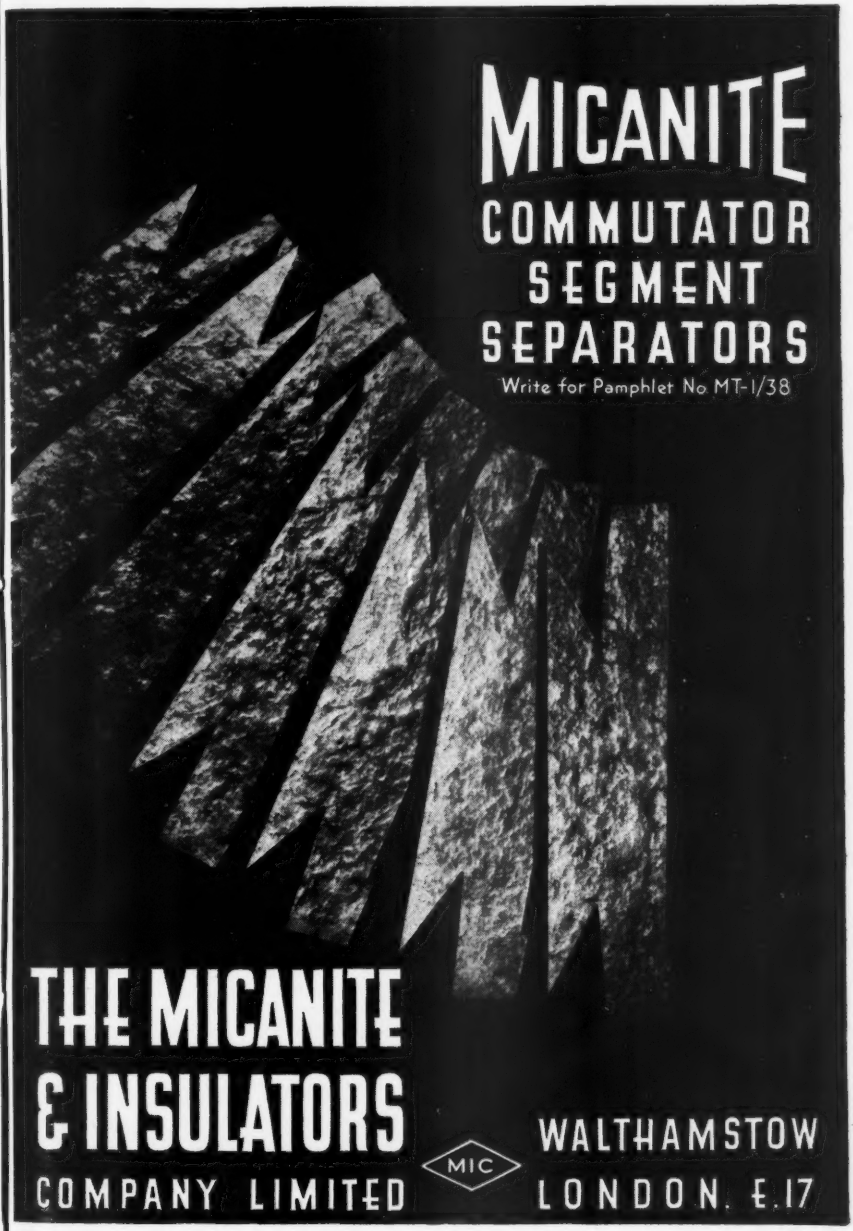
Institution of Mechanical Engineers.—A meeting will be held on December 10, at 5.30 p.m., at Storey's Gate, Westminster, when the following papers will be delivered:—"A Survey of Plastics from the Viewpoint of the Mechanical Engineer," by Dr. S. L. Smith; "Moulding Plant for Plastics," by Mr. J. L. Daniels.

PERSONAL

Major M. N. T. Gubbins, O.B.E., M.C., has been appointed to the Board of Directors of Lacrinoid Products, Ltd.

SIR MALCOLM FRASER, Bart., G.B.E., has been elected Chairman of Callender's Cable and Construction Co., Ltd., of Hamilton House, Victoria Embankment, London, E.C.4, and also of the Anchor Cable Co., Ltd.

Sir Malcolm Fraser was elected Director of these two Companies in 1923. He is also Deputy Chairman of Callender's Trust, Ltd. He has taken an active part in the development of this old and successful group of companies, especially in the direction of extending the scope of the business. In 1933 he visited India on behalf of the company to represent it at the opening of the Uhl River Electrical scheme in the Punjab by the Viceroy. For this scheme Callenders had carried out the distribution equipment.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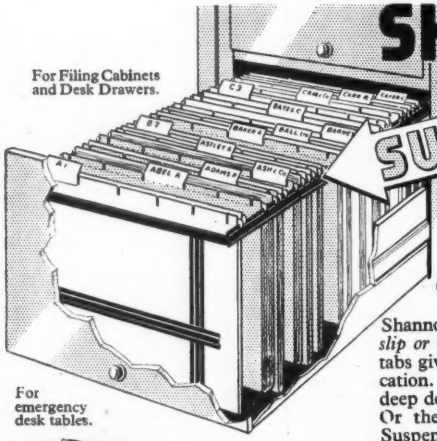

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BRITISH PATENT ABSTRACTS

556,364. **Application:** **13.1.43.** **Granted:** **1.10.43.** Improvements in or relating to the manufacture of Plastic Materials. Pilkington Bros. Ltd. and C. B. Joseph.

The plastic material claimed in B.P.545,421 and derived from keratin is rendered water resistant by the addition of a hardening agent such as formaldehyde during or after precipitations of the plastic.

556,373. **Application:** **8.7.43.** **Granted:** **1.10.43.** Labels. Wingfoot Corporation, Akron, Ohio.

A method of labelling bottles or other containers which consists in heating and stretching a band of thermo-stretching material, such as rubber hydrochloride, slipping the stretched band round the container and allowing it to cool in place.

556,721. **Application:** **5.5.43.** **Granted:** **19.10.43.** Improvements in and relating to the manufacture of plastic materials. Pilkington Bros. Ltd. and C. B. Joseph.

Materials, such as hair, feathers, bristles or wool, containing keratin are treated with an aqueous solution of sodium and/or potassium sulphides and a buffer to maintain the pH value of the liquid to a figure slightly above that required to effect solution of the keratin, the solid matter removed, and the plastic product precipitated by means of an acid. The pH is usually about 12.5 and the buffer a solution of amino-acetic acid, disodium hydrogen phosphate or sodium borate. The ppt. may be hardened by treatment with formaldehyde.

556,738. **Application:** **10.3.43.** **Granted:** **20.10.43.** Improvements in or relating to Methods of Coating Articles and of making Electrical Resistances. J. White.

Resistances formed of a hard body to support the conducting element of thin wire, such as are used in radio receivers, are usually coated with an artificial resin or a stoving enamel. In the former case the temperature required to polymerize the resin is usually about 120 degrees C., which is near the operating temperature of the resistance under full load and so is not sufficient to stabilize the resistance when working under these conditions, while with vitreous enamel finishes the temperature of 900 degrees C. or thereabouts gives rise to difficulties due to expansion. It is now proposed to use polyvinyl acetate or a polyglyceryl phthalate resin, heating to 180 degrees C. and thereafter periodically raising the temperature to between 250 degrees and 320 degrees C. and maintaining it at this level for some time. (B.P. Nos. 548,560 and 506,117 are acknowledged.)

556,743. **Application:** **13.4.43.** **Granted:** **20.10.43.** Improvements in and relating to the Production of Optical Lenses and other Moulding in Plastics. A. W. Kingston.

In the production of lenses, prisms, etc., from thermoplastic materials such as methyl methacrylate, the piece is first preformed by cutting or grinding to a shape closely approximating the final object, after which it is moulded in accurately made discs, etc., thereby enabling the products to be finished in closed moulds so that they are free from internal strains and will retain their optical properties even in varying conditions of moisture and temperature.

556,756. **Application:** **17.4.42.** **Granted:** **20.10.43.** Production of Condensation Products of the Formal type. British Celanese Ltd. Convention 17.4.41. Appln. U.K. 17.4.42. 20.10.43.

The condensation product of the reaction between an aldehyde and an aliphatic hydroxy compound is carried out by introducing a mixture of the two under the surface of the hydroxy compound previously heated to a temperature above the mean reaction temperature. Paraformaldehyde and ethylene glycol mono-methyl and ether are given as examples.

566,763. **Application:** **17.4.42.** **Granted:** **20.10.43.** Improvement in and relating to the Drying of Smooth, Non-fibrous Webs which are subject to shrinkage during treatment thereof. British Cellophane Ltd.

In order to prevent shrinkage of smooth non-fibrous webs during drying, the edges are folded over thin tenter belts before passing through heated rolls. The web is tentered during its passage by gripping in between rolls and the belts so as to prevent shrinkage of the web in a transverse direction.

Resinoids and Other Plastics as Film Formers

By B. J. BRAJNIKOFF,
Consulting Electrical Engineer

XXII.—High-Elastic Deformation of Polymers

AMONGST the multitudinous plastic materials now in use or on trial the rubber-like synthetics occupy a very significant place by virtue of possessing high elasticity, in addition to satisfactory overall characteristics. By high elasticity is meant the type of the extensibility exhibited by vulcanized rubber at ordinary temperature.

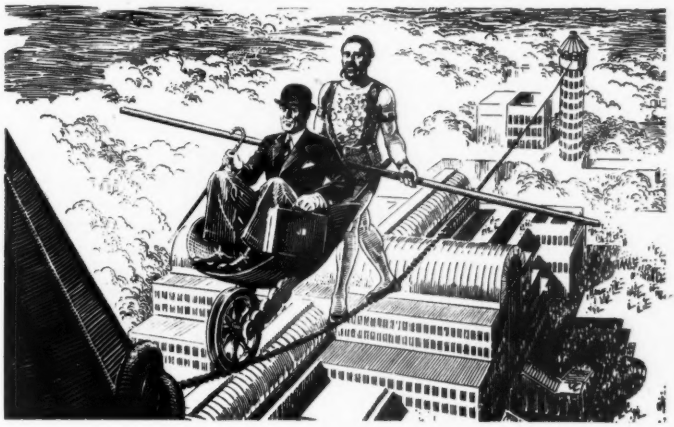
Whereas most solids show an elasticity not much in excess of 1 per cent., the rubber-like compounds, at suitable temperatures, may display an elastic range as high as several hundred per cent. The analytical consideration of the complex of mechanical properties of a film, comprising hardness, elasticity, adhesive power, tensile and other strength characteristics, resistance to impact, etc., under the proper tests, allow the evaluation not only of a general suitability of a film-forming agent as an adequate protective coating medium, but also the degree of its fitness for the special purpose in view.

Throughout this work attention was drawn to notable advances that have been achieved in recent years by various investigators in an attempt to correlate the composition of film-forming substances to their structural properties.

It may be remembered that the polycondensation class of resin, the typical examples of which are the phenolics, carbamides and alkyds, produce macromolecules characterized by a three-dimensional structure, displaying, side-by-side with infusibility and insolubility, only moderate tensile strength and low elasticity. As a rule, the incorporation of such resins into coating media is manifested by a decrease in the permeability to reactive vapours and liquids. The feature of the chain polymers is a two-dimensional configuration of their molecules. In the resin of this type the length of the molecular chain and the distribution of chain lengths effectively determine the physical characteristics of films derived from them. With extending length of the chain, the resin gains in tensile strength as well as in toughness, in consequence of which the majority of the resins of this class exhibit high elasticity at certain temperature levels. As would be expected, these plastics are much more temperature sensitive than are those belonging to the category of the three-dimensional structure. These differ greatly in their physical characteristics, as do the resultant films obtained from them. The coating compositions prepared from very long filamentary molecules are distinguished by the formation of tough films, which show both great tensile strength and high elongation. In general, it may be stipulated that the physical as well as the processing qualities of a polymer depend upon the length of the linear chain and upon the extent to which the cross-linked polymer is formed as opposed to that of the filamentary configuration.

Kinetics of the Relaxation Process of High-elastic Deformation of Polymers

During the past few years the most prominent aspects in the investigation of high-elasticity phenomena have been: (a) the development of the kinetic concept as to the nature of forces evolved in the process of high-elastic deformation, which was demonstrated by Meyer,[314] Kuhn,[315] Juth,[316] Mark,[317] and others; the kinetic idea affords the possibility for treating from the thermo-dynamical viewpoint of the diverse values for the modulus of high



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elasticity; and (b) the establishment of the relaxation character of high-elastic deformation,[318] allowing the possibility to judge with regard to kinetics of its attainment.

Unfortunately, so far there exists no generally accepted definition of the very term "high elasticity." The definitions of "high-elastic deformation," as expressed by its numerical value,[319] are not merely formal in character, but are even erroneous in essence: they fail to reflect the principal distinction between the mechanisms of an ordinary elasticity and that of high-elastic deformation, as may be seen from the following consideration. The modulus of elasticity as determined for the various values of deformation of high-elastic bodies (starting from elongations of the order 200 to 300 per cent. right up to deformations of the order of thousandth fractions of 1 per cent. obtainable in determining the velocity of sound in vulcanized rubbers[320]) gives small values, which are characteristic for high-elastic deformation. The yielding of large values of modulus, peculiar to non-high-elastic bodies, is governed not by the amplitude of deformation but by other factors.

Extensive information concerning the structural behaviour of high-elastic products, which also make possible the formulation of concepts of the mechanism of their actuation, should be accredited to Alexandroff and Lazurkin,[321] whose experiments within the past few years have contributed a great deal to elucidating the regularities observed in the processes of high-elastic deformation of polymeric bodies.

Distinction Between High and Low Elastic Deformation

According to kinetic conceptions developed by Kuhn, Juth, Mark and others, the main distinction between the ordinary and high-elastic deformation consists of the fact that whereas the usual deformation is associated with the variation of the mean distances between the particles, the high-elastic deformation is connected with the regrouping of particles without alteration of the average distance between them. Let us consider the scheme of both processes in greater detail.

In the absence of external forces, the mean distance between the particles of a body is determined, roughly, by the equality of forces of attraction and repulsion. In the case of the elastic deformation, the external forces disturb this equality. As a consequence of this unbalancing action there takes place an alteration of the distance between the particles of such a value that the resultant of all forces applied to each particle becomes, in the average, equal to zero. It is precisely on account of this that accumulation of the elastic energy takes place in the deformed specimen. As soon as the external force is removed the whole system returns to the initial condition, which corresponds to the minimum of free energy. Thus the phenomenon of the ordinary elasticity is primarily associated with the change of the distance between the particles.

An entirely different mechanism exists in the case of high-elastic deformation. In the absence of external forces in high-elastic substances, like in all amorphous bodies, at any given moment there may exist co-ordination in the distribution of the neighbouring particles, without, however, any macroscopic predominant orientation, i.e., the mean distribution is that of disorder. The external forces give rise to directed regrouping of particles. This regrouping of particles, mainly, results in (i) irreversible displacements, that is, in flow, and (ii) in displacements, which cause the occurrence of the directed arrangement of particles in the system.

The presence of such an orientation in the deformed high-elastic substances is corroborated by the studies of double refraction and X-ray data, as shown by Katz[322] and other workers.[323] The thermal motion of particles creates the tendency towards disturbing the orientation, which gives rise to the force that opposes deformation. On removing the external force, the thermal motion again

brings the system into a former disoriented state. In this case there takes place the restoration of the original shape by the body, the more complete the lesser the role played in it by irreversible regroupings. Assuming that the oriented and unoriented arrangements of particles are equivalent in terms of energy involved, it follows that the density of a substance in deformation of such a type as the flow remains constant. This is the physical essence of high-elastic deformation, according to notions of kinetic theory. Indeed, the constancy of volume in high-elastic deformation has been observed in rubbers,[324] bakelite,[325] and polyvinyl-acetate.[323] The presence of fillers and processes of crystallization yields superimposed effects that lead to the alteration of volume, which, however, can be accounted for.

None the less, the possibility should not be excluded that in certain substances the oriented and unoriented distribution of particles is not equivalent from the energy standpoint, as was correctly indicated by Houwink,[326] which circumstance should be taken into consideration in the further development of the theory of high elasticity.

In simple amorphous bodies the reversible displacement of the particle is limited by molecular dimensions. Therefore, in employing the ordinary methods of observation, the deformation associated with the orientational regrouping is always accompanied by a very large plastic deformation of flow. In polymers the reversible displacement of a particle (of separate links of the polymeric chain) is restricted by the length of macromolecule, i.e., by a considerably greater value. The term " reversible " as used here is meant not in the thermodynamical sense, since such displacements are always associated with the dissipation of energy, but understood to mean that on removing of external forces the body spontaneously regains its original shape. The irreversible deformation is strongly handicapped by the circumstance that for attaining the flow there is required the regrouping of macromolecules as a whole, relative to one another. For this reason, as the degree of the polymerization increases, and particularly in the formation of three-dimensional polymers, the role of irreversible deformation falls. The principal part is constituted by the deformation, associated with the reversible process, owing, mainly, to the orientational regrouping of particles.

Analytical Considerations

Under the action of the external force on the body, the latter undergoes deformation of both types, i.e., of elastic and high-elastic kind, with the result that the observed general deformation constitutes their sum total. The proportion of one and another deformation is determined by the ratio of their respective moduli. In deformation balancing an applied force (that is, non-varying with time), the total deformation is constituted by

$$D = D_{el.\infty} + D_{el.} = \frac{1}{E_{el.\infty}} + \frac{1}{E_{el.}} = \frac{1}{E} \quad (1)$$

where D, $D_{el.\infty}$ and $D_{el.}$ signify the values, which are reciprocal to the corresponding moduli, and are proportional to the relative deformations (at a given intensity of applied pressure): E denotes the stretch modulus or Young's modulus, characterizing the elastic share of deformation, $E_{el.\infty}$ represents the modulus of high-elastic deformation, and E the total modulus.

In this event, $D_{el.\infty}$ is conditioned by the average degree of orientation, which is determined by the statistical equilibrium between the orienting influence of the external field and the disorienting action of thermal motion of the system. So long as it is possible to neglect the variation of the mutual energy of particles, the external field may be considered as the sole factor that conditions the orientation. In the case of rubbers at low temperatures,[318] when the process of orientational regrouping of particles progresses very slowly, with the application of the force for a short period, we merely observe $D_{el.} = \frac{1}{E_{el.}}$, where $E_{el.}$ reaches 40,000 kg./cm.^{2}.

In evaluating the modulus of the natural (free from fillers) rubber at room temperature, we obtain values of the order of 20 kg./cm.^{2}, i.e., 2,000-fold smaller. Hence it may readily be seen that at room temperature levels the deformation of the rubber is associated, mainly, with the process of regrouping of particles and proceeds with the preservation of the constancy of volume. With a lesser value of the moduli ratio, when the ordinary elastic deformation constitutes a substantial part of the general deformation of a body, the change of the volume should be more considerable.

Thus the observed deformation of an elastic substance can, schematically, be represented as consisting of the two components, differing by mechanism of their actuation.

The elastic deformation obeys general laws, which have been sufficiently well investigated in relation to metals and other materials. With regard to the time the elastic deformation, irrespective of temperature, proceeds in phase with the variation of the applied force, and the value of its modulus very little depends on the temperature (corresponding with relatively small change of density with the temperature).

The high-elastic deformation is associated with regrouping of particles, and, therefore, in time it lags behind the varying force: it is displaced in phase over a certain angle, depending upon the mobility of particles. This phase displacement may also be deduced on the grounds by taking into account the internal friction of the system, which is evoked by the interaction of neighbouring particles, the consideration, that the kinetic theory usually disregards.

The Computation of High-elastic Deformation

The balancing value of high-elastic deformation can be calculated on the basis of concepts relating to some definite model, as it has been shown by Kuhn, Guth and Mark. According to these notions, $D_{el.\infty}$ is found somewhat dependent on the temperature, which influences the mean degree of orientation. However, this dependence, which, according to Mark, may be expressed by

$$E_{el.\infty} = \frac{1}{D_{el.\infty}} = \frac{7RT}{M}\rho, \qquad (2)$$

(where R denotes gas constant, M—molecular weight, ρ—density, T—absolute temperature), is not very pronounced. The usually observed influence of the temperature on deformation of rubbers is associated, basically, with the kinetics of attaining a high-elastic deformation.

The probability of passing, under the action of chaotic thermal motion, of a particle from the position A into the position A^1, for which it is necessary to overcome the potential barrier U, is equal to

$$W = Ce^{-\frac{U}{kT}} \qquad (3)$$

where C is some coefficient, k—the Boltzmann constant, and T—absolute temperature. The value U of the potential barrier depends upon the chemical nature of a substance and its density and depends somewhat on the temperature.

Under the application of deforming forces, the process of regrouping acquires the definite direction and leads to the diminution of stresses produced within a body during deformation. The process of relaxation of the stresses in a deformed body, as evolved by Maxwell, represents a classical example of macroscopic adaptability of substance to the external action due to irreversible regrouping of particles. All processes, whose course in time is determined by the probability of regrouping of particles under the action of the thermal motion, will be subsequently termed here as the relaxation processes.

Furthermore, the relaxation processes, which are associated with irreversible regroupings, reduce the stress value in the specimen to zero. The relaxation processes, which are connected with the emergence of a definite predominant orientation, diminish the stresses within the body to a certain finite value, at which a further process of orientation is balanced by the disorienting action of thermal motion.

The velocity of the most diverse relaxa-

tion processes is proportional to the probability of regrouping of particles W, i.e., the value

$$e^{-\frac{U}{kT}},$$

the numerical magnitude of which with the rise of the temperature rapidly grows. This fact has been discovered for the phenomena of high-elastic deformation in the work of Kobeko, Kuvshinsky and Gurevitch,[318] who showed that the total value of the elastic deformation of rubber does not depend very much on the temperature, but the velocity of its attainment to a great extent depends upon temperature, as may be seen from Fig. 1; this precisely testifies to the fact that the deformation of a high-elastic substance

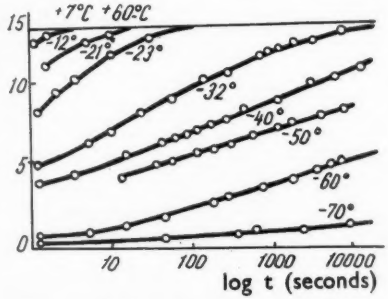

Fig. 1.—Relation of velocity of attainment of elastic deformation with temperature.

represents the reversible relaxation process.

As has been stated previously, the total deformation of a body which is balanced at a given force is characterized by the expression

$$D = D_{el.\infty} + D_{el.}$$

In order to describe the course of the process of the elastic deformation we must introduce into this equation, in place of the finite balanced value $D_{el.\infty}$, the value $D_{el.t}$. The dependence of the latter quantity on time $D_{el.t} = f(t)$, determined by experiment, is very complex and, generally, depends somewhat on the history of the specimen. Since the mathematical treatment of the elastic deformation, involving highly complicated functions, aids very little to clear the physical picture of the phenomena, Alexandroff and Lazurkin have found it far more useful to confine the analysis to a rough approximation by taking into account the fact that the relaxation process, in attaining a high-elastic deformation, under the action of a constant force, obeys the well-known exponential law, i.e., that

$$D_{el.t} = D_{el.\infty}\left(1 - e^{-\frac{t}{\tau}}\right).$$

In this expression t denotes the time from the moment of the application of force up to the moment of the registered value of the deformation, and τ—the time of relaxation of the elastic material, depending upon the probability of the regrouping of particles:—

$$\tau = \frac{A}{e^{-\frac{U}{kT}}} = Ae^{\frac{U}{kT}} \qquad (4)$$

Hence, for the total deformation we arrive at the equation:—

$$D(t, T) = D_{el.} + D_{el.\infty}\left(1 - e^{-\frac{t}{\tau}}\right) =$$

$$= D_{el.} + D_{el.\infty}\left(1 - e^{-\frac{t}{Ae^{\frac{U}{kT}}}}\right) \qquad (5)$$

This expression will form the basis in all subsequent schemes for describing the dependence of the deformation of elastic substances on the temperature T and the time t, from the moment of applying the force until the moment of recording the characteristic deforming effect it produced.

The nature of the dependence of the deformation on time and temperature, in accordance with the equation (5), is presented in Fig. 2.

The dependence of the deformation on the time of the force action at various temperatures (the left part of the Fig.) and the dependence on the temperature at different intervals of time of the action of the force, as derived from the formula (5), is clearly shown.

Such a character of the relationship between the applied force and deformation (the elaboration of the deformation law with a greater precision merely

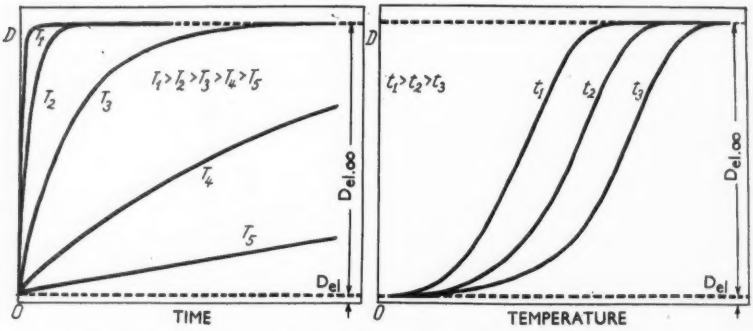

Fig. 2.—Deformation of elastic substances with time and temperature.

changes its details) leads to a very important practical conclusion: even approximate characteristic of the elastic properties of a material should contain two parameters—the temperature and the time of the application of force (or in the case of periodical forces—the duration of period or the frequency).

Thus, on the basis of defining the deformation of elastic bodies as the sum total of the elastic and high-elastic relaxation components, it is possible to obtain the schematic regularity, which determines the dependence of the deformation of elastic substances on the time of the action of forces and the temperature. Such a relationship corresponds to the curves of deformation by torsion derived experimentally by Kobeko and his co-workers referred to above.

(To be continued)

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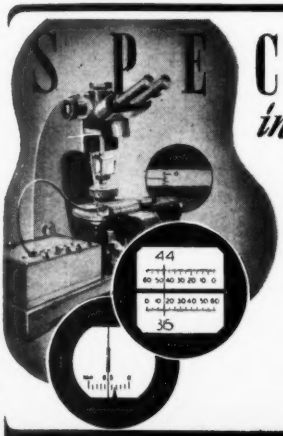

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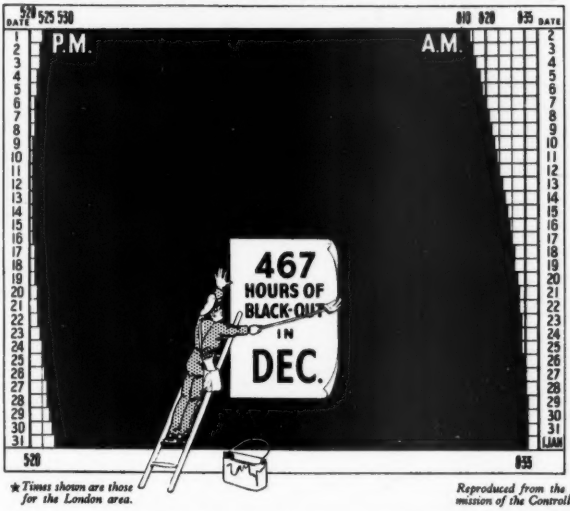

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